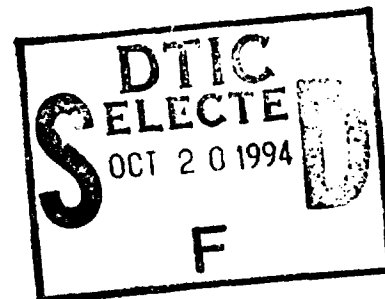94-9SL2-LAFIL-R1

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PROCESSING, FABRICATION, AND DEMONSTRATION OF HTS INTEGRATED MICROWAVE CIRCUITS

S. H. Talisa and J. Talvacchio
Cryoelectronic, Crystal and Electro-Optical Technology
Program Manager, Dr. G. R. Wagner

September 29, 1994

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Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217-5000
Project Manager, Dr. W. A. Smith

94-32630

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R&D STATUS REPORT

ARPA Order No.: 7932   Program Code No.: htsc 051-101

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Principal Investigator: G. R. Wagner

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Short Title of Work: Processing, Fabrication, and Demonstration of HTS
Integrated Microwave Circuits

Reporting Period: 4/25/94 to 7/24/94

DESCRIPTION OF PROGRESS

TASK 1.0: COMPARATIVE TECHNOLOGY ASSESSMENT

This task is essentially complete, but we are continuing to monitor progress in other technologies as they relate to the goals of this program.
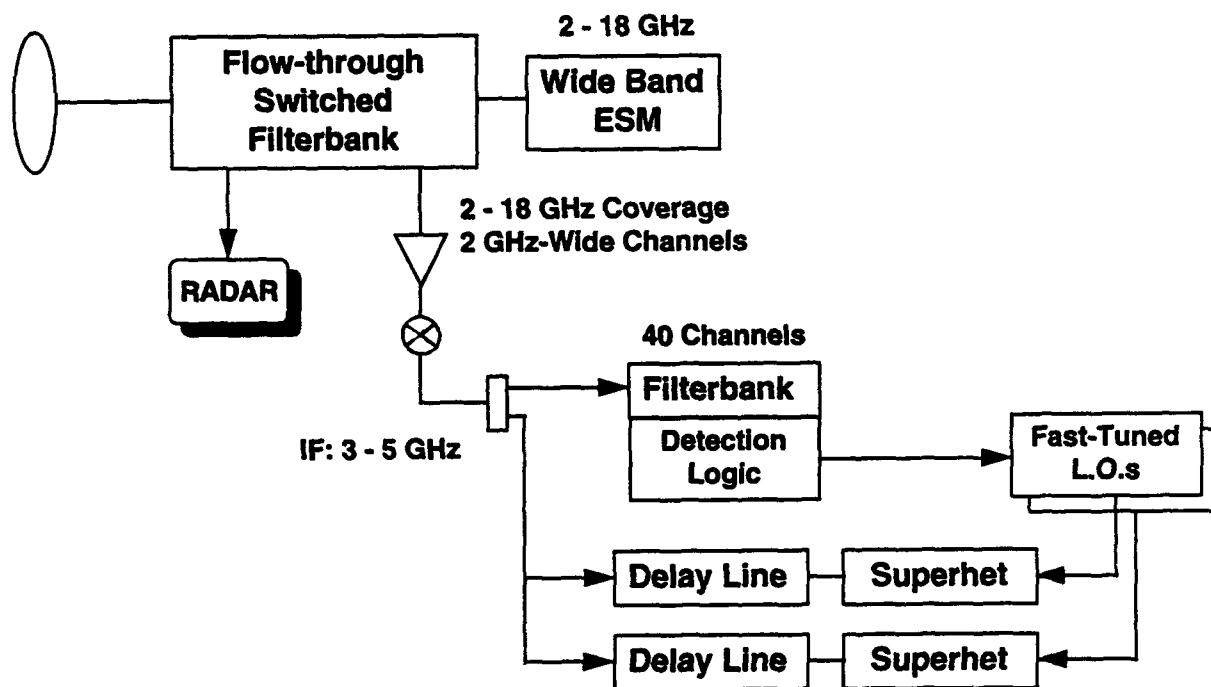
TASK 2.1: INTEGRATED SUBSYSTEM SPECIFICATIONS

An ESM receiver analysis was completed in this reporting period and is included here as an appendix. It is a rigorous analysis on the benefits of the use of HTS components in ESM systems. The basis for the study is a comparison of sensitivity and dynamic range between a typical ESM/ELINT receiver, using the best available current technology, and the same system using HTS components. The HTS components identified as key for insertion into ESM systems are: delay lines, filter banks and front-end flow-through switched filterbanks. In addition, a future HTS or semiconducting cryocooled mixer has been presumed.

The "typical" ESM system chosen for this study is a Channelized Cued Receiver architecture with two receiver threads: A channelizer and a narrow-band superheterodyne receiver. Once the base-line performance of both threads was determined, the insertion of HTS devices one at a time and then in combinations was considered. The delay line was analyzed for two different gain distributions. The analysis included a complete optimization of receiver gain and sensitivity distribution and the gain (or loss), noise figure and third-order intercept points of all the components in the chain.

Figures 1 to 3 summarize the study. Figure 1 is a block diagram of the Channelized Cued Receiver with the HTS components (shaded). Figure 2 is a table showing the HTS device parameters used in the analysis. These were taken from experimental measurements and performance projections. Figure 3 shows the results of the study. The last column on the right shows the improvement in system performance due to the insertion of the HTS components. As can be appreciated, this improvement is significant.

HTS Shared Aperture System

Figure 1.   Block diagram of Channelized Cued Receiver used in system study.
The receiver is shown here in its conceptual use in a Radar/ESM
shared aperture.

HTS Component Parameters

	Frequency Range (GHz)	Loss (dB)	NF (dB)	IP3 (dBm)
Delay Line	3 - 5	3.6 (@ 5 GHZ)	1.3	40
Filter Bank	3 - 5 40 Channels	6	2.5	40
Switched Filter Bank	2 - 18 8 Channels	3.2	1.1	40
Down-Converter:				
Mixer	2-18 to 3-5	4	1.5	30
Band-Pass Filter	3 - 5	0.2	0.05	40

SHT
ew_atd
9/7/94

Westinghouse
Science and Technology Center

Figure 2.   HTS parameters used in ESM system study. These were obtained from measurements of devices made in this program and calculated performance projections.

ESM Receiver Analysis Summary

		Baseline AESM	HTS	Difference
Channelizer	**Sensitivity**	-72.3 dBm	-77.4 dBm	+5.1 dB
	TTDR	46.8 dB	50.5 dB	+3.7 dB

Superhet	**Sensitivity**	-70.5 dBm	-76.6 dBm	+6.1 dB
	TTDR	44.3 dB	49.5 dB	+5.2 dB

Figure 3   Summarized results of the HTS ESM system study showing
            sensitivity and two-tone dynamic range (TTDR) for the base-line
            conventional receiver and the same receiver when HTS components
            are included. Notice that the improvements (last column on the right)
            are significant.

TASK 2.2: FUNCTIONAL COMPONENT AND SUBSYSTEM DESIGN, FABRICATION AND TESTING

<u>Filterbanks</u>

HTSSE-II Filterbank and Delay Line Delivered.

Deliveries were made to the Naval Research Laboratory, under the parallel HTSSE-II program, of a space flight 4-channel filterbank and 45-ns delay line units. All the technology employed in those devices was developed under this ARPA/ONR program. Figure 4 shows the response of all four channels of the filterbank delivered. A photograph of the device with the lid open was included in our Quarterly Report No. 10. Figure 5 is a photograph of the 45 ns delay line, showing the two modules in series that make up the total delay. Figure 6 shows the frequency and time-domain responses for this device.

Ground Plane Problem

Our investigations on the optimization of our filterbank channel responses continued during this reporting period. Further experimental evidence led us to the conclusion that the quality of interface between the substrate ground plane (2-μm-thick electroplated gold), and the carrier needs to be improved. The soldering process used for mounting the substrates on the carrier was reviewed and found inadequate. SEM, ultrasonic and X-ray analyses were conducted on various samples to determine the quality of the interface. Optical examinations on several disassembled devices showed large areas on substrate and carrier where some type of reaction had taken place between the indium and gold but it was evident that the substrate was not attached to the carrier in these areas. X-ray diffraction analysis established that there was no elemental gold left in these areas, only $AuIn_2$, a brittle intermetallic compound. We believe the presence of this higher melting point, hard compound as a large area interface layer precludes obtaining good electrical or mechanical interface properties because it has poor electrical conductivity and because its formation interferes with the ductility of the preferred indium layer, thus making it easier for thermal strains to peel the substrate away from the carrier. Actual soldering of the gold

Insertion Loss (dB)
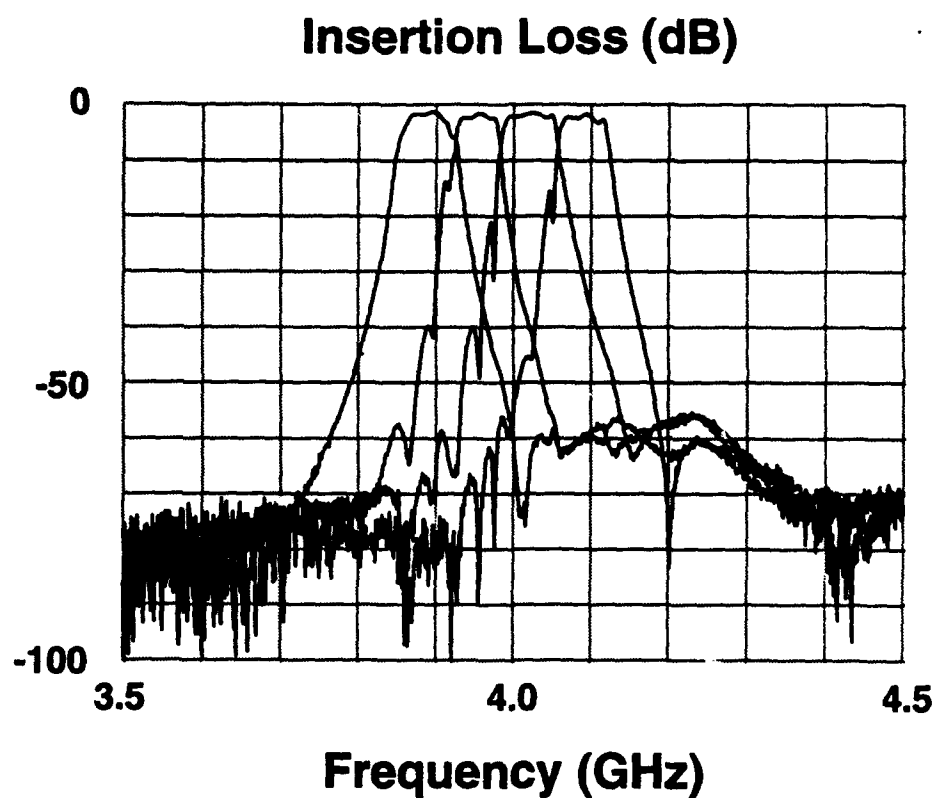
Frequency (GHz)

Figure 4   Composite plot of the response of all four channels of the HTS
filterbank delivered to NRL (Flight device). The notches on the lower
frequency skirts of channels 2, 3 and 4 are the effect of multiplexing
and occur because of overlapping with the previous channel.
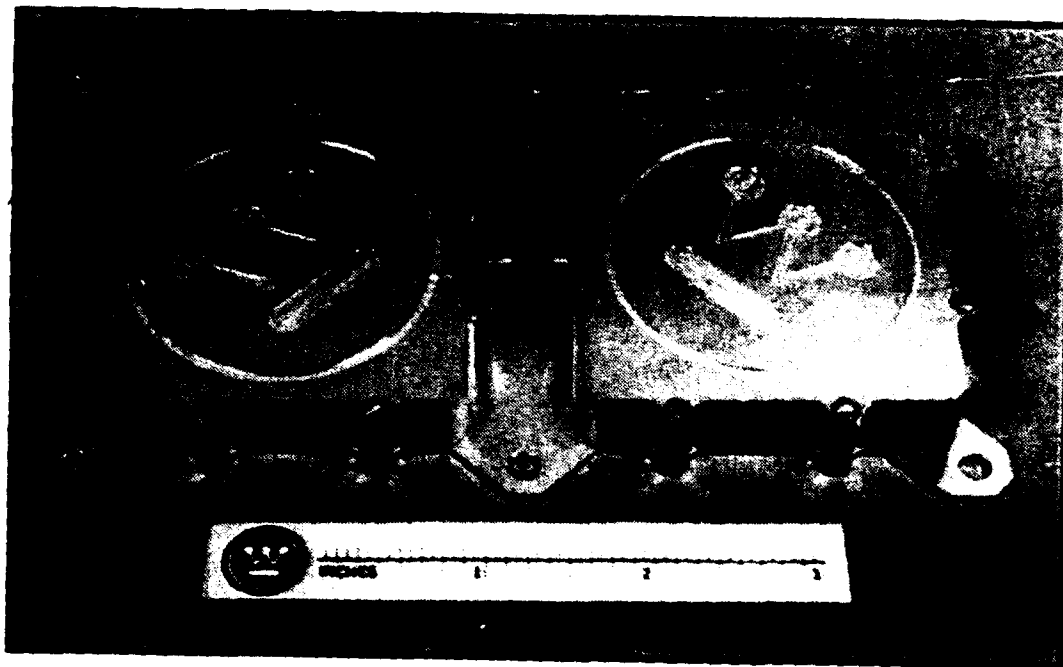
Figure 5   Photograph of the HTS 45 ns delay line showing the two 22.5 ns
modules connected externally through the male-female coaxial
connector pair.

8

▶S₂₁   log MAG
REF 0.0 dB
    10.0 dB/

896-049

C
R

H

START   2.0000000000 GHz
STOP   6.0000000000 GHz

(a)

▶S₂₁   lin MAG
REF 0.0 Units
1   100.0 mUnits/
∇   841.7 mU

896-049

*
C
R

MARKER 1
    45.0 ns
13.491 m

H

1

START -1.0 ns
STOP   49.0 ns
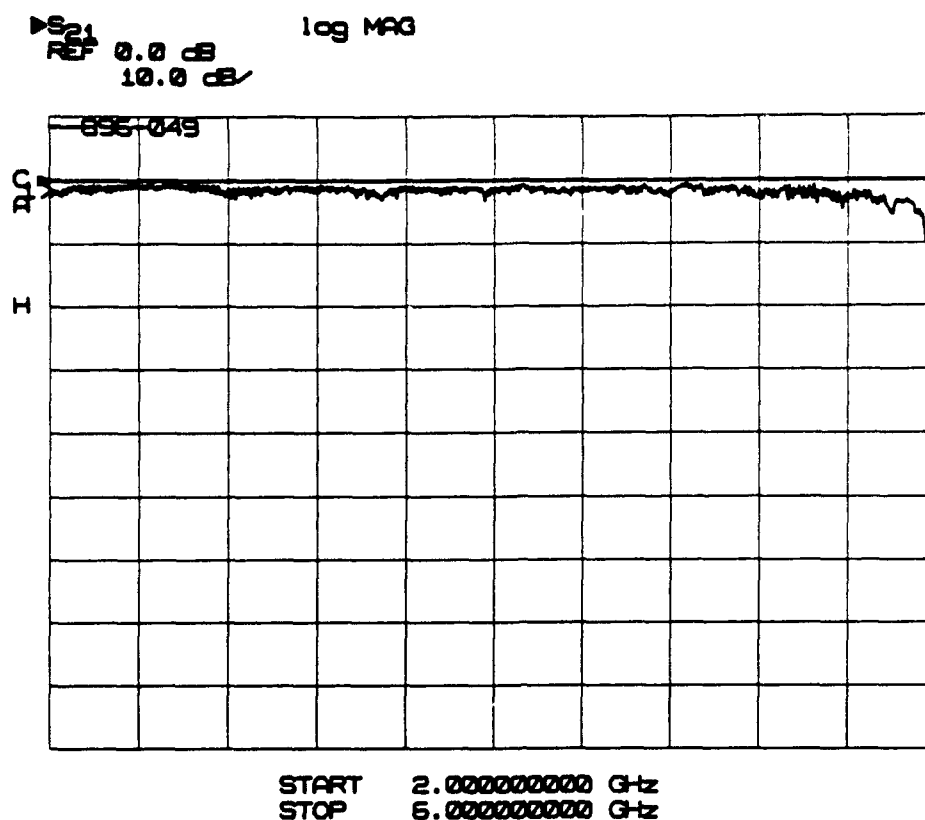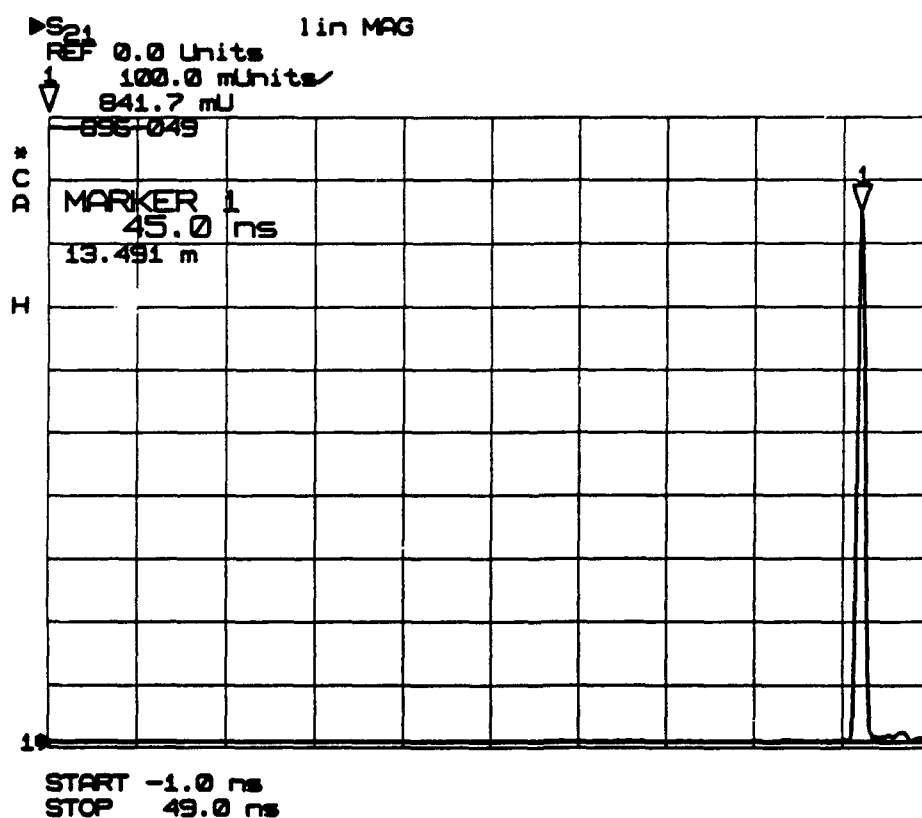
(b)

Figure 6   HTS delay line frequency-domain response between 2 and 6 GHz (a)
and time-domain response showing the total delay (b).

9

plated substrate to the gold plated carrier requires using a solder where the formation of these compounds is inhibited. The usual solder choice for soldering gold plated surfaces of semiconductor substrates (usually much smaller) to carriers would be a lead-indium or silver-indium alloy with a higher melting point and less ductility. These solder compositions are not as suitable for cryogenic temperature use, where solder ductility is more important. Higher melting point, vigorously wetting solders are also contraindicated when YBCO underlies the gold surface, because diffusion of indium through the gold layer to the YBCO will harm the HTS properties of the film.

The successful ground plane connection achieved with our earlier, smaller devices was most probably due to a large area pressure contact between two gold surfaces with an indium layer in between. During assembly, the indium was melted and about one-half squeezed out. This resulted in a good electrical contact due to compression of the edges of the substrate against the carrier.

To achieve good electrical contact for larger area substrates using a similar technique, we tested a modified assembly procedure for the stripline delay line (2" diameter wafers). Indium preform layers were placed between the substrates and the carriers, maintaining compression on the assembly while heating it in vacuum to just below the melting point of indium, thus using the increased indium ductility to produce a conforming, large-area pressure contact. The pressure was maintained after to the heating cycle by the assembly fasteners. Very good electrical properties were obtained.

It is more difficult, however, to maintain pressure on a large microstrip filter substrate without interfering with the microwave field distribution above the device. Various arrangements using springs are presently being explored. Some tests will also be performed with conductive adhesives containing large percentages of silver powder.

ARPA Filter Fabrication and Testing.

The testing of the design of the four-channel filterbank for EW applications was begun with the fabrication of single filters from the third

channel. The procedure for the design of these filters was discussed in our Quarterly Report No. 9. Two wafers were processed with two single filters each. Measurements were done, preliminarily, on a test fixture designed to provide quick measurement turnaround and a better understanding of the packaging requirements. The response is shown in Figure 7, which also shows the desired ideal response and the one obtained from an electromagnetic simulation (using the Sonnet™ software) on this geometry. As can be seen, the measured response is 78 MHz below the designed one. This problem is presently being investigated. It must be pointed out that the design technique used for this filter is the same as for the filters made for the parallel HTSSE-II program, where, at most, differences of less than 5 MHz were observed between measurements and design. In Figure 8 the measured response has been shifted in frequency so as to lay on the designed responses (ideal and Sonnet). It can be seen that the agreement between passband shapes is very good down to about 45 dB. This is an encouraging result which will impact favorably on the time-domain response of the filters when multiplexed into an EW filterbank. The effect of the lower filter skirt below 45 dB is presently under investigation, as is its correction.

Tandem Coupler with Gold Ribbon Crossovers

The wide band tandem coupler reported in our Quarterly Report No. 9 is now being fabricated after some refinements in the design were made to account for the size constraints imposed by the total channel dimensional requirements. That is, the distance between the two 8.34 dB couplers that form the tandem was shortened and the input lines were rotated by 90° from the original design. The layout of the channels was designed so that it would fit in the substrate area used in the parallel HTSSE-II program, using the same locations for the input/output connectors. This will allow the use of the same basic design for all the test packages and the channelizer as was used previously for the HTSSE-II devices. A mask was designed to test the coupler design with three couplers per 2-inch diameter wafer. Two wafers are in process and will be completed shortly. The couplers will use gold-ribbon crossovers.

Figure 7. Superposition of measured and designed responses for the single Cos³ filter fabricated. Of the two responses labeled as "Designed," one is the ideal response and the other was obtained from an electromagnetic analysis of the final geometry used.
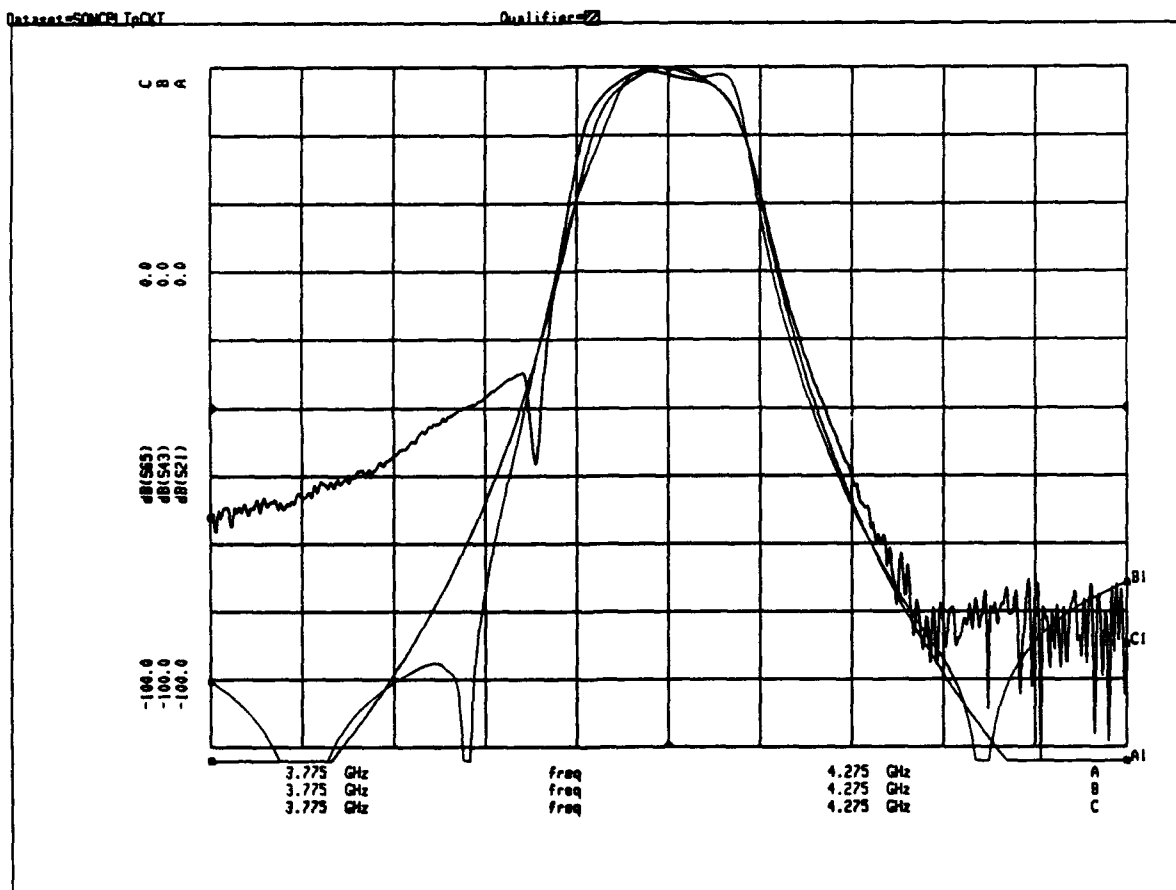
Figure 8.　Same as Figure 7 with the measured response shifted to lay on the designed curves.

Tandem Coupler with YBCO/SAT Trilayer Crossovers

A version of the tandem coupler using YBCO trilayer crossovers is also in the final stages of design. A trilayer technology developed on an Air Force (AFOSR) program will be applied for this tandem coupler. The trilayer is made up of a base YBCO on $LaAlO_3$ (LAO), an intermediate Sr_2TaAlO_6 (SAT) dielectric 2000 Å thick and a top YBCO layer (2000 Å). It is expected that higher reliability and lower loss per coupler will result from this effort, as well as lower production costs. It must be pointed out that a four-channel filterbank will have a total of 16 crossovers (two tandem couplers per channel; two crossovers per tandem coupler). Thus using gold ribbon in a practical channelizer (40 channels or more) is not possible. Furthermore, this technology will have a significant impact on the crossovers needed for lumped element spirals which, as pointed out below, might ultimately be used for EW channelizers. Figure 9 shows details of the layout. Figures 10 (a) and (b) are the calculated transmission and reflection characteristics, respectively, obtained to date.

Lumped Elements

An effort was begun in this quarter to develop techniques for filter design and fabrication using lumped elements. The reason is that as our work in this program reveals more clearly the impact of HTS on EW systems, achieving compact filterbanks has acquired increased importance. The lumped element approach to practical EW filterbanks must be contrasted with our present distributed element design which demands one 2-inch diameter wafer per channel. It is expected that using planar lumped elements the channel sizes can be reduced considerably, making the channelizer smaller and the fabrication more cost effective.

The work will initially concentrate on basic filter designs and test structures at frequencies lower than 4 GHz, where the filterbank operates. Being designed are two versions of an L-band filter and some test resonating structures which will be used to evaluate inductive and capacitive lumped elements.
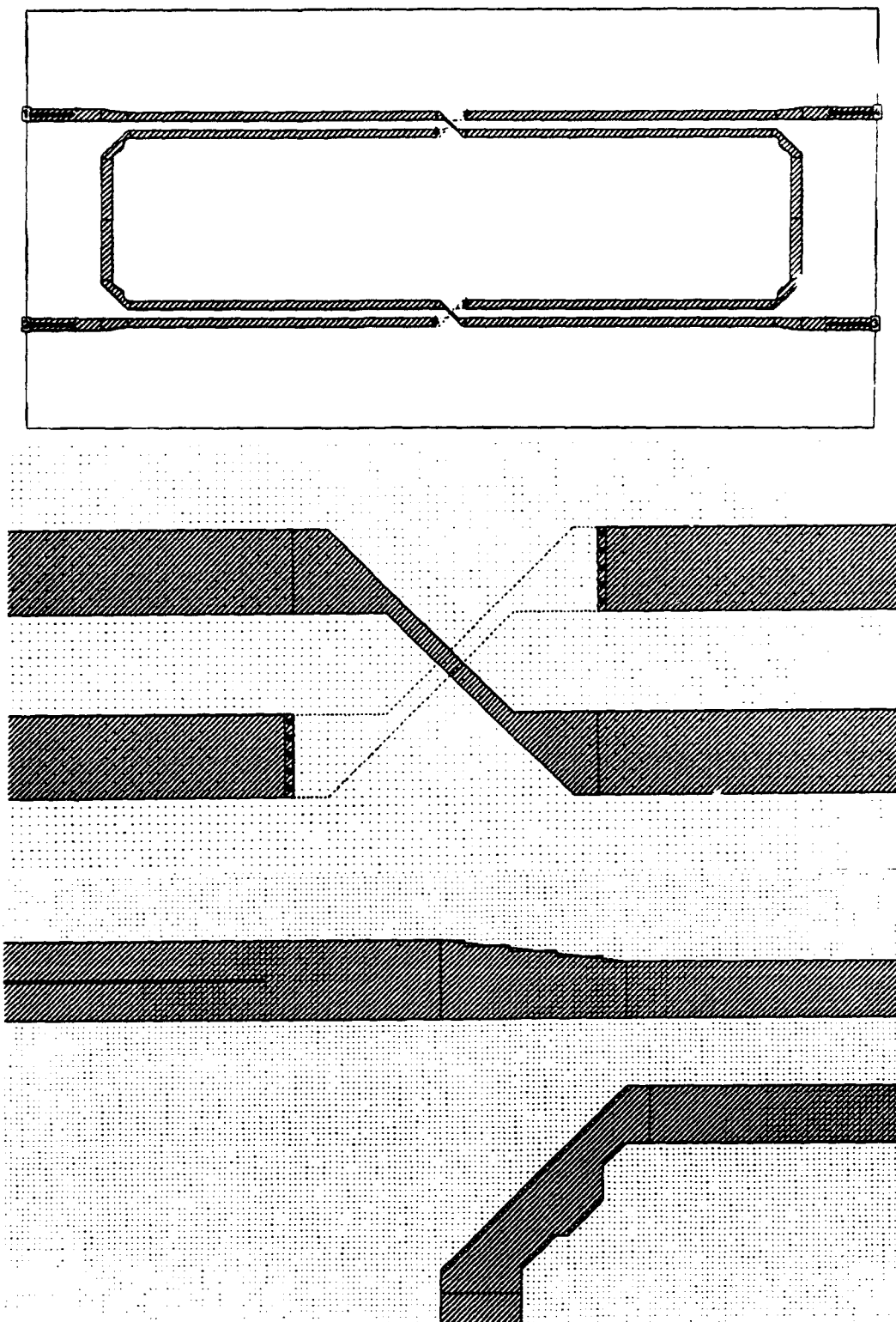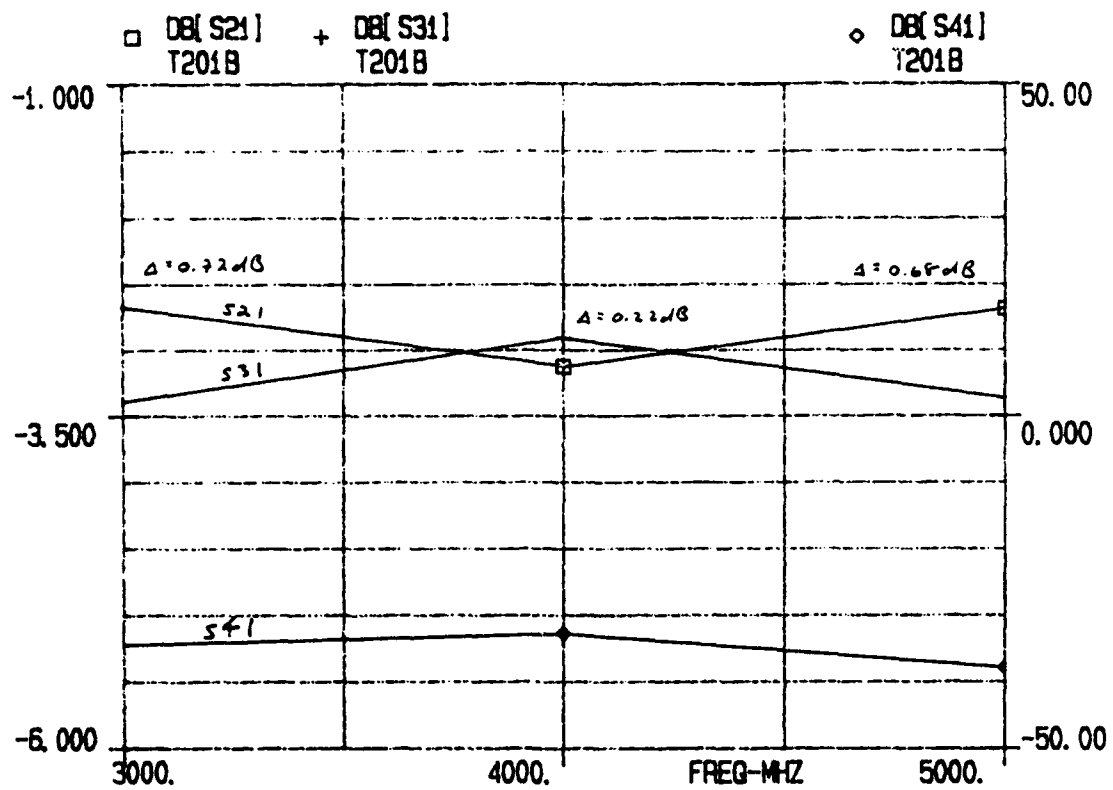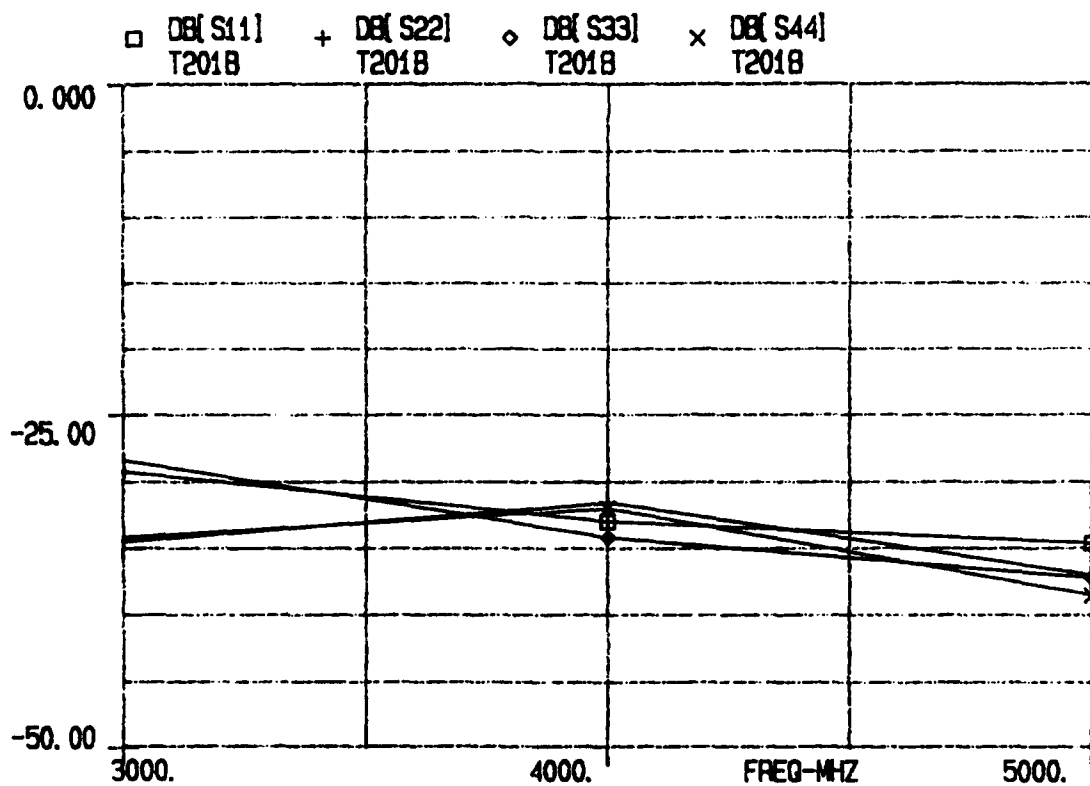
Figure 9. Details of the layout of the tandem coupler with YBCO/SAT crossovers.

Figure 10. Calculated transmission (a) and reflection (b) for the tandem coupler with YBCO/SAT crossovers.

The specifications of the filter are based on the requirements of a single channel in a switched filter bank used in an L-band radar currently being produced in several variations (ship-based, aerostat-based). The design is a five pole Chebychev, centered at 1305 MHz, with a 10 MHz bandwidth (0.8%). The main design, which will be labeled Topology 1, is based on shunt coupling inductors, with grounding on the top surface of the filter substrate (i.e. a coplanar structure is used), with no back-side ground plane. This design includes tunable capacitors for adjusting the center frequency of the filter to account for small material or process variations. A second filter, Topology 2, was designed with a microstrip configuration (i.e. there is a back-side ground plane) using shunt coupling capacitors. This design will not be tunable and hence will be a good indicator of the variations in the process and materials.

These filter designs have been completely modeled using the Libra linear simulator (which also provides the layout). The spiral inductors will be fabricated and evaluated prior to fabricating the complete filter. The test circuit for the spiral consists of the spiral in parallel with a known standard American Technical Ceramics type 111 capacitor, and a spiral in parallel with an interdigitated capacitor. Final layout is nearing completion, with the addition of coplanar waveguide input lines to these test patterns. Key elements of the filter designs are being simulated by Sonnet, an electromagnetic simulator. This is essential on some parts of the circuit as the Libra models are inadequate. The simulations from the Sonnet runs are then substituted for the linear Libra models.

The lumped element ideal filter prototypes with the shunt coupling inductor (Topology 1) and shunt coupling capacitor networks (Topology 2), along with their responses, are shown in Figures 11 and 12, respectively. The series inductors were implemented using spiral inductors; the series capacitors with adjustable piston capacitors from Voltronics (for Topology 1) or two microstrip gaps in series (for Topology 2). The shunt inductors are two parallel lines shunted to a coplanar ground on the top substrate surface. The shunt capacitors were designed as pads of a given width and length on the top surface of the substrate.

□ DB[S21]   ÷ DB[S11]
  FILTER   FILTER

$C1 = 22.5349$ PF

$C2 = 2.75362L$

$C3 = 2.44178$

$C4 = 2.448473$

$L1 = 6nH$

$L2 = 0.05329$

$L3 = 0.037$

0.000

-35.00

-65.00

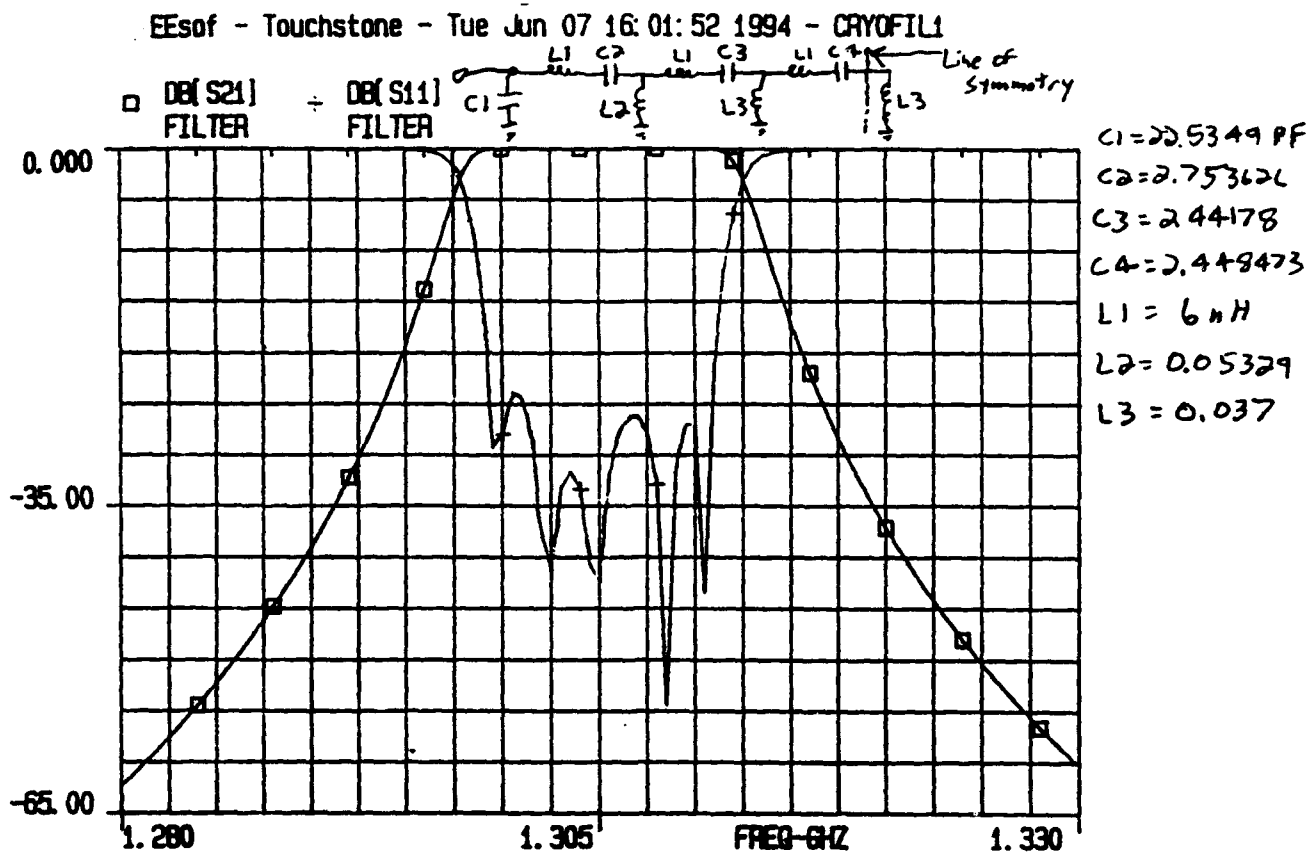1.280   1.305   FREQ-GHZ   1.330

Figure 11. Ideal filter prototype and its response for the lumped element filter with Topology 1.

18
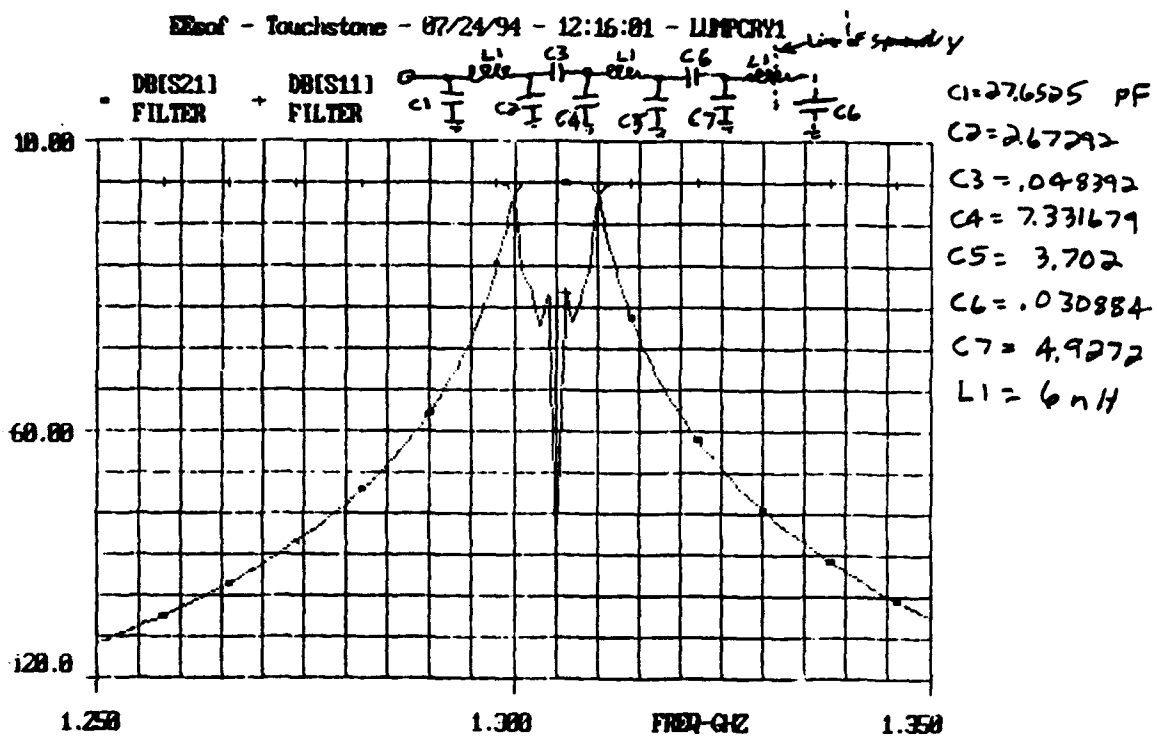
Figure 12.   Ideal filter prototype and its response for the lumped element filter
with Topology 2.

The shunt inductor topology (Topology 1), was found to require a suspended substrate configuration with a coplanar ground in order to minimize stray capacitances. The pad size needed for the trimmer capacitors, about 3100 μm square, would provide about 4 pF of shunt capacitance if the substrate were not suspended. Even with this feature, it was determined that the resonance frequency of a single spiral resonated with an ideal fixed capacitor is very sensitive to the proximity of the package surface below the suspended substrate.

The effects of finite inductor and trim capacitor Q on Topology 1 (Figure 11) were also examined, as shown in Figures 13 and 14. The filter insertion loss is most affected by the Q of the spiral inductors. The insertion loss and passband shape in a filter with this designed percentage bandwidth (0.8%) are very sensitive to element Q.

In the next reporting period the resonator test circuits will be fabricated and the results compared with our simulations. Also, the Sonnet simulations of both topologies will be completed. Only Topology 2 will be analyzed completely in Sonnet because it is a well defined microstrip geometry. Topology 1, which includes the trimmer capacitors, will have only some of its elements, specifically the inductors, analyzed in Sonnet.

TASK 3.1: PVD MULTILAYER FILM FABRICATION

The two subtasks scheduled for this reporting period required delivery of YBCO films on both sides of two-inch diameter substrates to Task 2.2, and development of a multilayer deposition capability on four-inch wafers.

Sputter-deposition of YBCO films on 2-inch wafers stayed ahead of device fabrication requirements. Several steps were made in this quarter to improve the reproducibility of R_s from wafer to wafer and thickness uniformity across a wafer. The improved performance reported last quarter for YBCO targets has continued. The vendor of YBCO targets, SSC Inc., has eliminated the inhomogeneities from targets that can cause the plasma to concentrate at a particular point on the target's surface and burn a hole through the target. This permitted us to focus on control of wafer temperature and oxygen pressure,
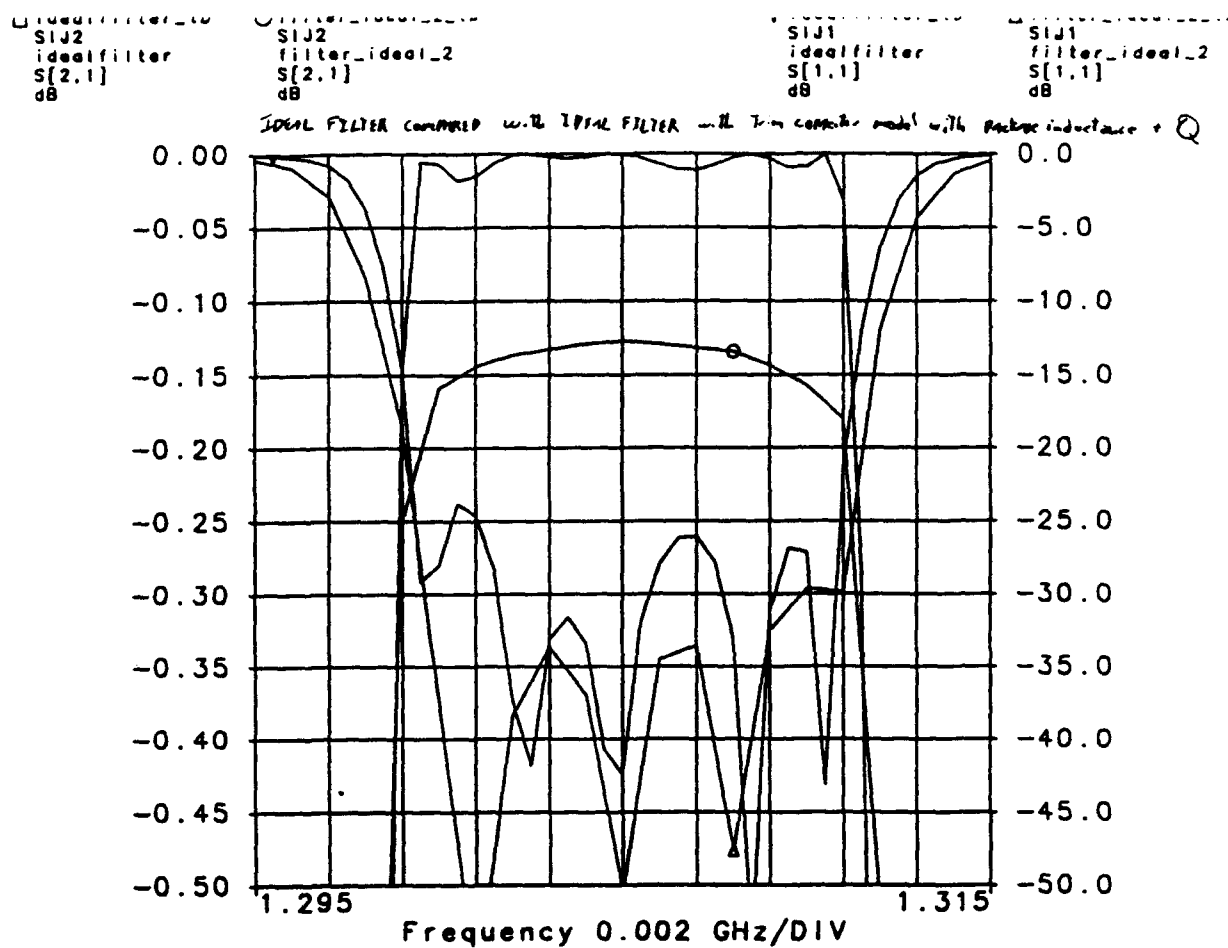
Figure 13. Effects of trim capacitor package inductance and Q on Topology 1
filter response.

IDEAL Filter, but with trim cap parkor inductance +Q and shunt inductor Q=1000

Frequency 0.002 GHz/DIV
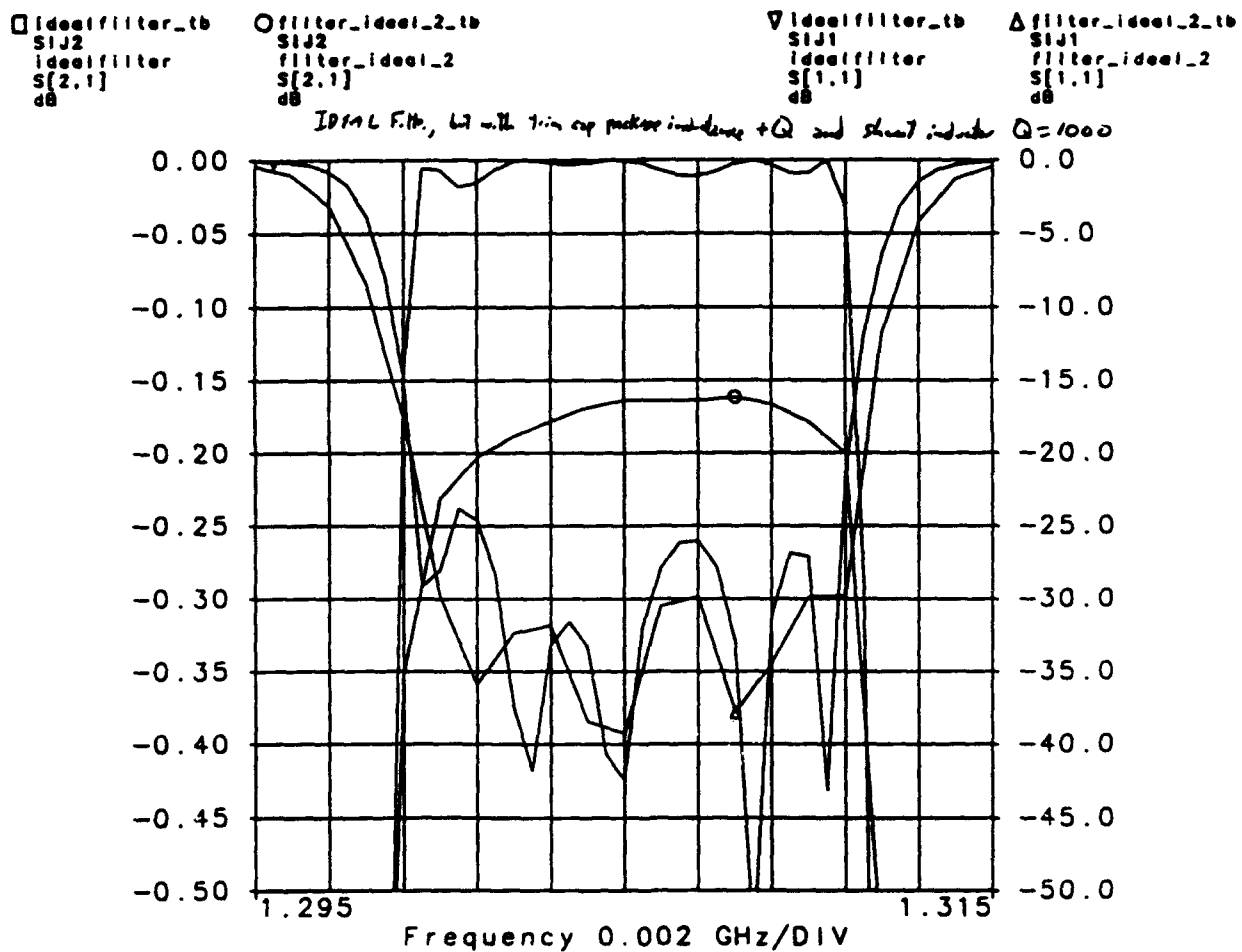
Figure 14. Same as figure 13 but including a shunt inductor Q = 1000.

which together determine the optimum growth location on the oxygen phase diagram of YBCO (shown in Figure 8 of Status Report #10). At issue is whether a post-anneal in a tube furnace is required to reproducibly obtain the target combination of oxygen partial pressure and temperature or whether it can be obtained during growth despite heat from the film surface radiating into the large volume of the growth chamber. The indication from rf surface resistance measurements on the last 15 films grown in the reporting period is that the extra annealing step is not required. However, since the surface resistance measurement is non-destructive, we will continue to measure every film before patterning devices.

Film thickness requirements are relative to the penetration depth of c-axis-oriented YBCO at 77K of approximately 300 nm. To obtain 1.5 times the penetration depth - 450 nm thick - at the edge of a 2" wafer, we had to deposit to a thickness of 600 nm at the center. We have found that the height of a lip in the substrate heater that shields the edge of the wafer and holds it in place is responsible for the thickness non-uniformity. A flat substrate holder was designed and will be put into service at the start of the new quarter. The thickness profile obtained with the present holder is shown in Figure 15. Although this films are thinner than those used for microwave devices, this figure shows that the thickness profile is independent of the material being sputtered.

A new sputtering chamber built to a Westinghouse design by Nordiko Ltd., which can accommodate 2, 3, or 4-inch wafers, became fully operational during the previous quarter. Its operation had been delayed by overheating of vacuum seals during long deposition sequences. Nordiko's latest modifications were successful in giving us a leak-tight system that can withstand the heat load imposed on it. The first three films grown in the new chamber — on 2" wafers — had R_s(77K, 10 GHz) < 1 mΩ (although corrections for film thickness less than a penetration depth had to be made for two of them). During this quarter, experiments were performed to increase the deposition rate. The rate is sufficient to proceed to growth on larger wafers.
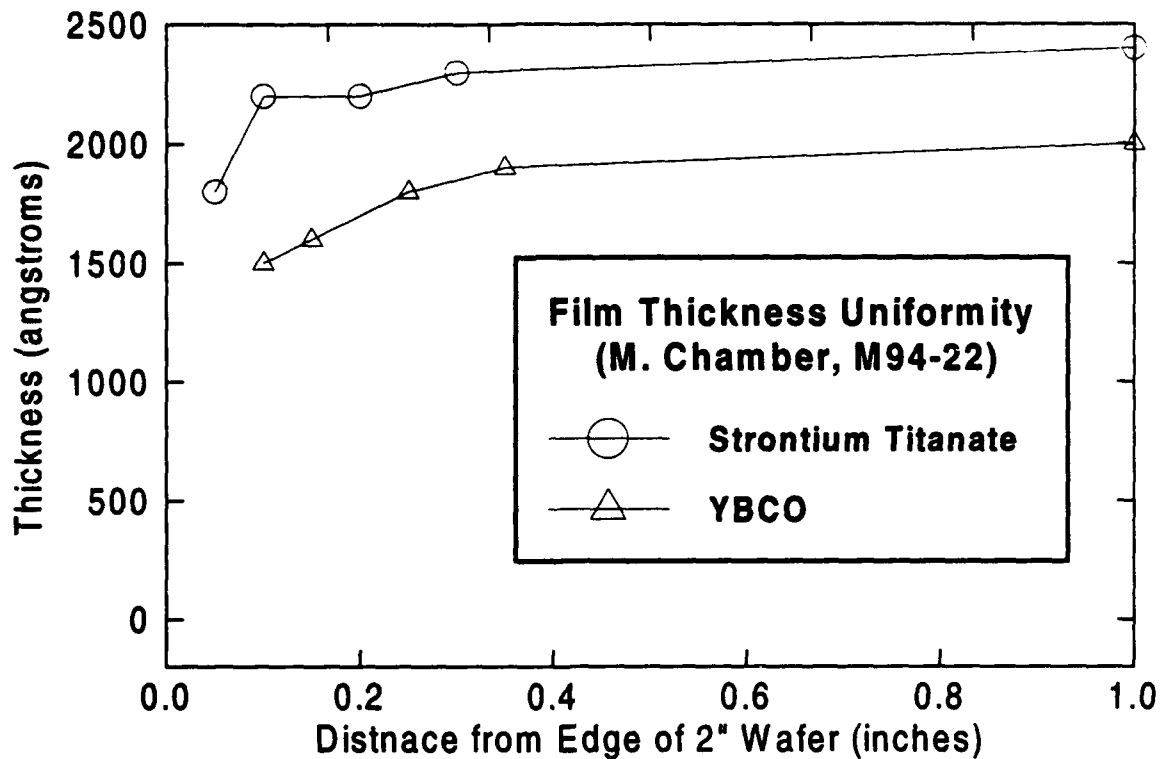
Figure 15. The thickness profile obtained with the present holder for 2" diameter substrates. Although these films are thinner than those used for microwave devices, this figure shows that the thickness profile is independent of the material being sputtered

TASK 3.2: MOCVD MULTILAYER FILM FABRICATION

The rf surface resistance of YBCO films deposited by MOCVD on both sides of 2" diameter by 0.020" thick substrates was measured at Westinghouse. The indication from these measurements is that Emcore can meet the requirements for microwave device fabrication with every film. However, for MOCVD films to be used in the EW demonstration, we need to show that the same film quality can be obtained on 0.010" thick wafers. Emcore is behind schedule in delivering test wafers on these thinner substrates.

The Ba-thd precursor used at Emcore for all YBCO films grown during the quarter was supplied by Northwestern University. Emcore will not start their evaluation of the new more-volatile precursors, bis(tri-butylcyclo-

pentadienyl)barium, (CptBu3)2Ba, and bis(di-butylcyclo-pentadienyl)barium, (CptBu2)2Ba until a backlog of double-sided 2" × 0.010" wafers is produced and a low-R_s 3" film is demonstrated.

Work at Northwestern University has shifted to liquid precursors which offer better long-term vapor-pressure stability simply by maintaining a constant surface area as they sublime. The results of using b-diketonate polyglyme ligands to coordinate the Ba ions have been published in the journal, *Chemistry of Materials*. The compound, $BaCF_3CF_3(CAP-3)$, has been found to sublime at 150°C and 10^{-6} torr without decomposition. Crystals were grown of the compound so the crystal structure could be determined. The structure determined by x-ray diffraction is shown in Figure 16. A molecule of DMSO solvent is coordinated at each of the two sulfur ions. In the coming quarter, $BaPbO_3$ films will be grown at Northwestern to complete their evaluation of this precursor before testing it with YBCO growth at Emcore.

TASK 3.3: RF CHARACTERIZATION OF FILM PROPERTIES

RF surface resistance measurements were made during the quarter on a total of 76 YBCO films on 2-inch wafers for a rate of approximately six per week. Measurements were used either to ensure that sputtered films were qualified for device fabrication or to evaluate films made by MOCVD at Emcore.

The standard measurement of R_s employs a dielectric resonator with a reference YBCO film on a 2" wafer and a film to be measured. Two such resonators are in use with reference films having R_s(77K, 10 GHz) = 0.55 ± 0.04 mW and 0.49 ± 0.04 mW, respectively. A similar accuracy is expected for low-R_s films (≈0.5 mW) and better accuracy for higher-R_s films since losses from the reference film become less significant.
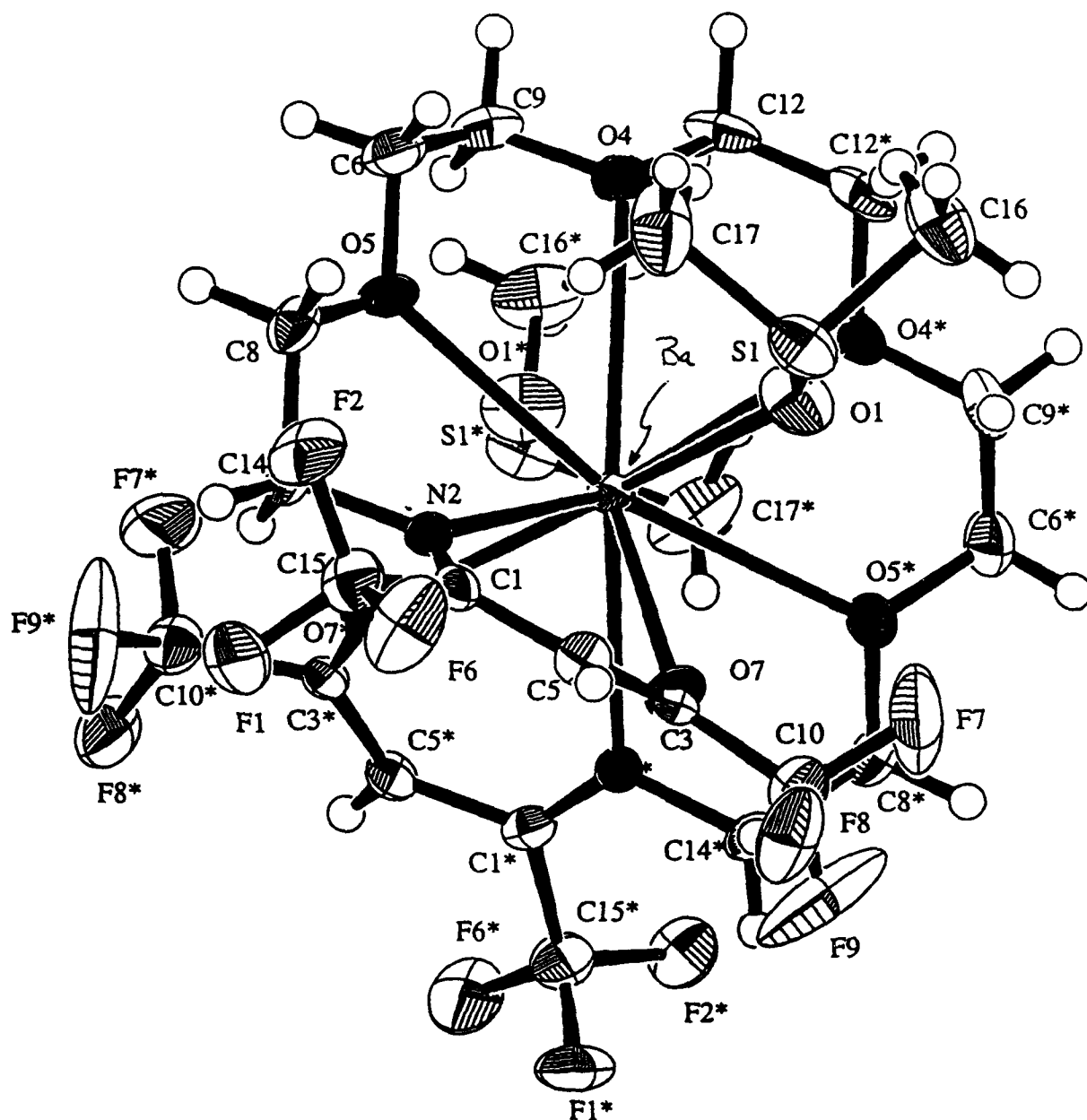
Figure 16. The structure of the Ba precursor compound, $BaCF_3CF_3(CAP-3)$, based on x-ray diffraction measurements of a single crystal. A molecular of DMSO solvent is coordinated at each of the two sulfur ions. This compound has been found to sublime at 150ºC and 10^{-6} torr without decomposition.

TASK 5.0: SWITCHED FILTERBANK

In this reporting period the fabrication of a wafer lot with several switch designs began. The lot comprised eight GaAs wafers, four of which had a suitable AlGaAs etch-stop layer for the fabrication of the etch-back FET switches. As mentioned in our last report, several switch designs were included which used normal FETs. This was done in order to make direct comparisons with etch-back FET switches and establish their advantages. A diagram showing the distribution of switch design patters on a wafer is given in Figure 17. Each rectangle labeled 6735 represents a reticle of switch designs and process control test patterns. The reticle size is 9600 μm by 8500 μm. The reticle is stepped off as a 7 by 7 rectangular array, with 8 reticles near the corners of the array deleted. Thus, the total number of reticle sites on the wafer is 41. The devices in each reticle are given a row and column identification label. The (1,1) site is in the upper left corner of the array.

Figure 18 is a photograph of the reticle showing its layout. The reticle is a 3 by 5 array of device dies. Each die site is 3200 μm by 1700 μm. The length of the switch from the RF input to the RF output is 3000 μm. The width of the switch from the DC ground via to the -5 V/0 V DC switch control signal pad is 1500 μm. The scribe lane is wider than usual (200 μm vs. 100 μm) to allow room for a dicing saw blade. The RF input and output bonding pads are flanked by grounded pads to create a ground-signal-ground footprint for RF wafer probing equipment. The RF pads are 125 μm squares on 170 μm center-to-center spacing. The DC bond pads are 200 μm squares. A typical switch device was shown schematically in our Quarterly Report No. 10.

The top two die sites in the first column of the reticle contain alignment marks and test patterns that can be measured several times during the switch process flow. The process control monitor (PCM) measurements are made on a DC automatic wafer probe station. There are also test FETs for RF measurement of R_{on} and C_{off}. The RF measurements are made when the wafers have completed topside processing, that is, before lapping to their final 100 μm
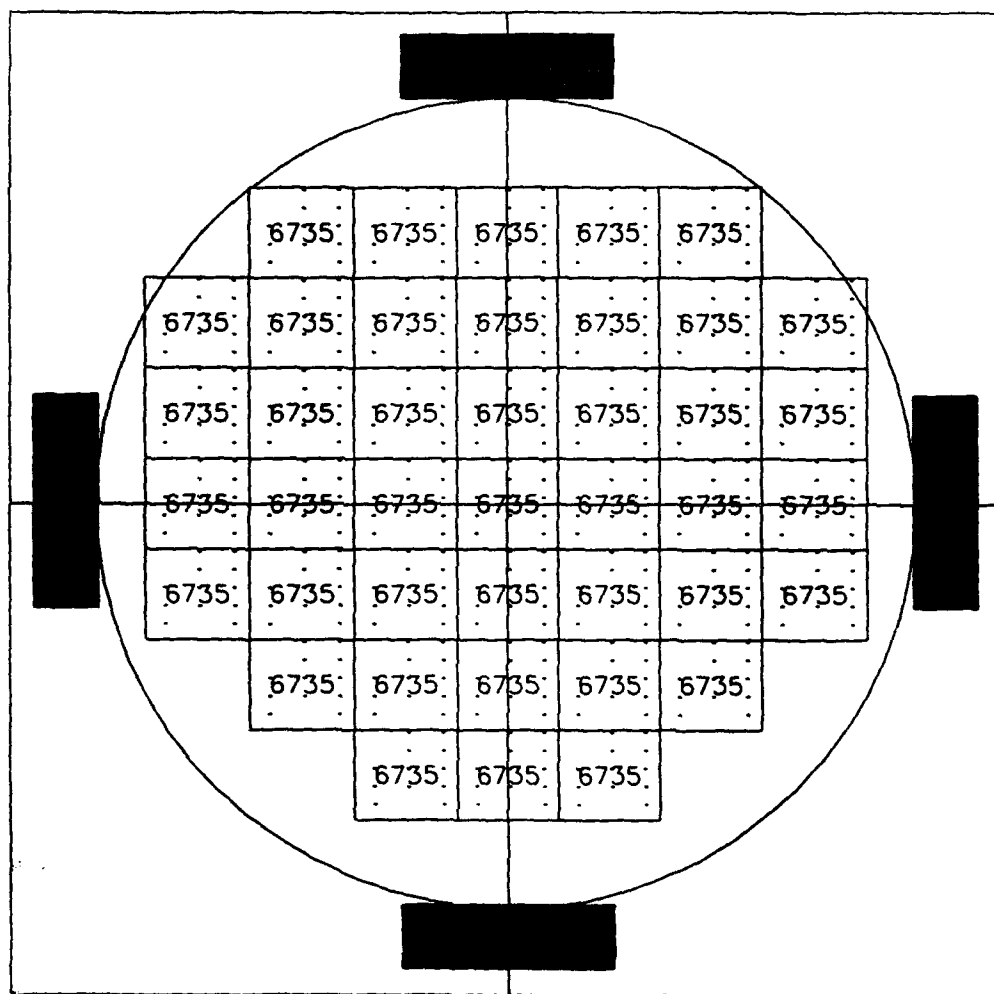
Figure 17   GaAs wafer map showing the reticle distribution. The same reticle is stepped throughout the wafer as shown. A reticle contains 12 switch designs as well as various test patterns.
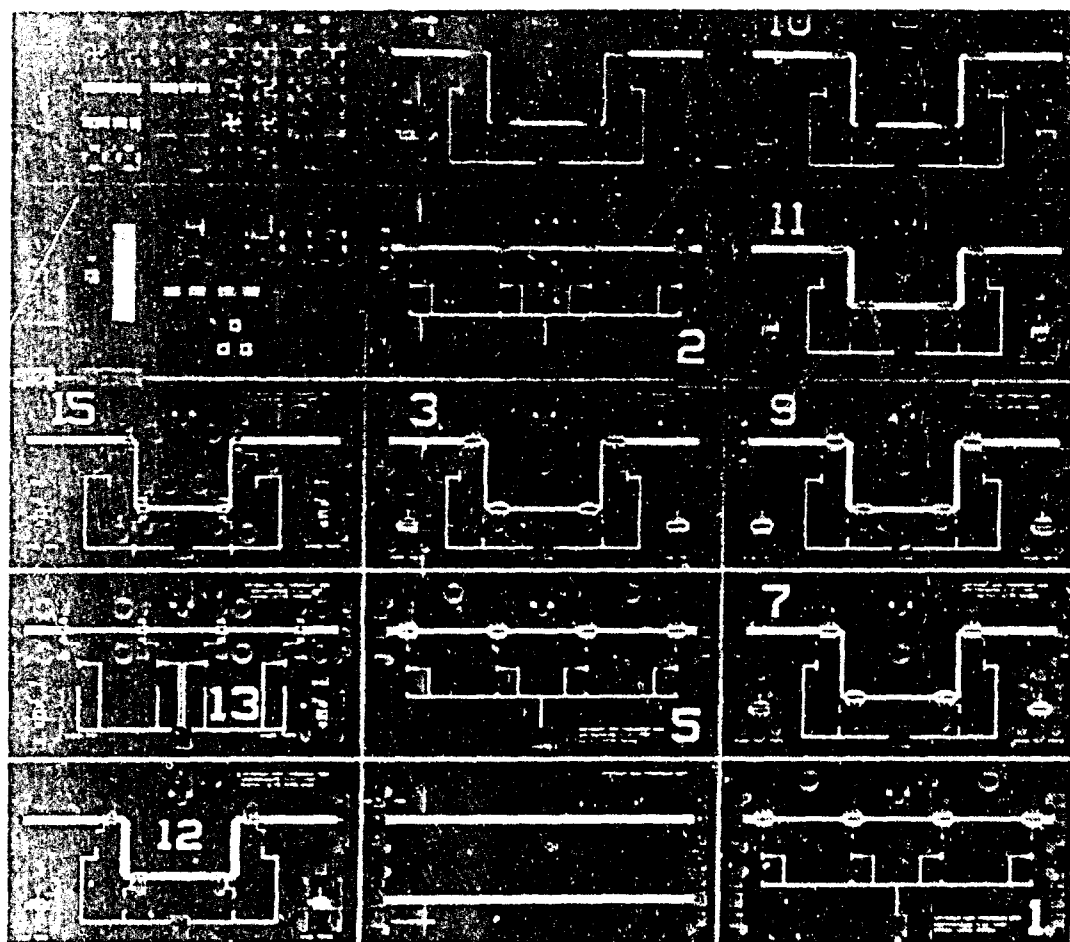
Figure 18   Photograph of a fabricated reticle from a "conventional" wafer (i.e. no etch-back FETs).

29

thickness and before the ground vias fabrication or backside metallization. The RF wafer probe measurements are made on a different station from the DC wafer probe measurements. The DC test signal can be brought down to the PCM pads with flexible needle probes. The RF test signals have to be transmitted through special probe heads.

Besides the two sites of the reticle described above, the other sites are occupied by switch designs except for one site that is simply an RF through (i.e., a 50 ohm line connecting the input and output). It is worth noting that in the bottom right corner of the reticle there is an isolation test pattern (i.e. input and output pads without any connection between them). The 12 switch designs are summarized in Table 1.

The fabrication lot is composed of eight wafers. The lot identification number is 1562. The first three wafers (namely 1562-1, 1562-2, and 1562-3) are conventional switch profile wafers. The conventional profile wafers do not have membranes beneath the FETs. The other five wafers in the lot have an etch stop layer that allows the membranes to be formed.

The status of the lot is:

(a) 1562-3 was broken and scrapped.

(b) 1562-5 was incorrectly processed at the air bridge fabrication step. The error was corrected but this wafer is not expected to be as good as the others.

(c) 1562-1, 2 have completed processing and some RF measurements have been made on certain devices. See below.

(d) 1562-4, 5, 6, 7, 8 are ready for etching the membranes.

(e) An experiment was performed on a blank wafer to test the membrane process. The resulting vent lines were wider than desired. There was also a problem with the alignment marks. This mask level was modified to correct these problems. Wafer 1562-5 will be used first to test this process (see item (b)).

Tests performed to date on the processed wafers are quite encouraging and close to our design goals. Figure 19 is a plot of R_{on} vs. C_{off} made with data

30
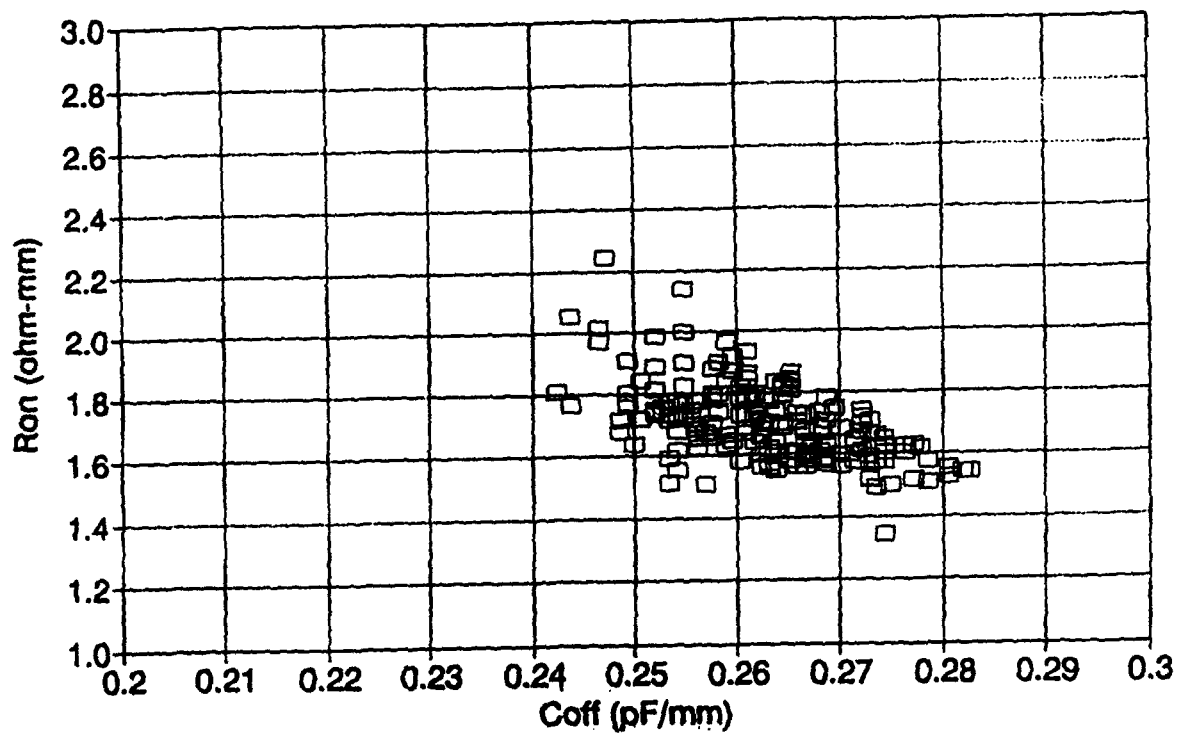
Ron_vs_Coff
L1562

Figure 19. R_{on} vs. C_{off} plot from data taken on seven wafers after completion of top side processing. Design goals were $R_{on} = 1.8 \ \Omega$ and $C_{off} = 0.26$ pF.

taken at room temperature on the test FETs of seven wafers after all the top side processing was completed. The design goals were $R_{on} = 1.8\ \Omega$ and $C_{off} = 0.26$ pF. After etching the FET backs, C_{off} is expected to be reduced by half. As can be seen, good agreement with the design goal was obtained.

Measurements at room temperature were made on the conventional switch profile wafers (i.e. wafers 1562-1 and 1562-2). In particular, device number 2, shown in Figure 20, yielded excellent results as summarized in Figure 21 for wafer 1562-1. Similar results were obtained for Wafer 1562-2.

Table 1 - Etched-Back FET Switch L6735
Summary of Designs on Reticle

Label on Die	FET Gates[1]	Shape[2]	Features
1	6X100	IM	Nominal design
2	6X50	IC	Nominal design
3	6X100	UM	Nominal design
4	6X50	UC	Nominal design
5	6X100	IM	Source via moved away from membrane
6[4]			Label number not used[4]
7	6X100	UM	Source via moved away from membrane
8[4]			Label number not used[4]
9[3]	6X135, 6X80	UM	High isolation design
10[3]	6X57, 6X40	UC	High isolation design
11[3]	6X70, 6X55	UM	Low insertion loss design
12[3]	6X35, 6X27	UC	Low insertion loss design
13	2X280	IM	Etch pit divided into two section, above and below transmission line
14[4]			Label number not used[4]
15	2X280	UM	Same as 13

Notes:
(1) 6x100 means six gates approximately one hundred microns wide. Gate length is 0.5 μm
(2) Design shapes:
   - I transmission lines form straight path.
   - U transmission lines form U-shape.
   - M membranes under FET.
   - C no membranes under FET.
(3) Designs 9 through 12 use two types of FET
(4) Some dies on the reticle have test patterns that were not given label numbers
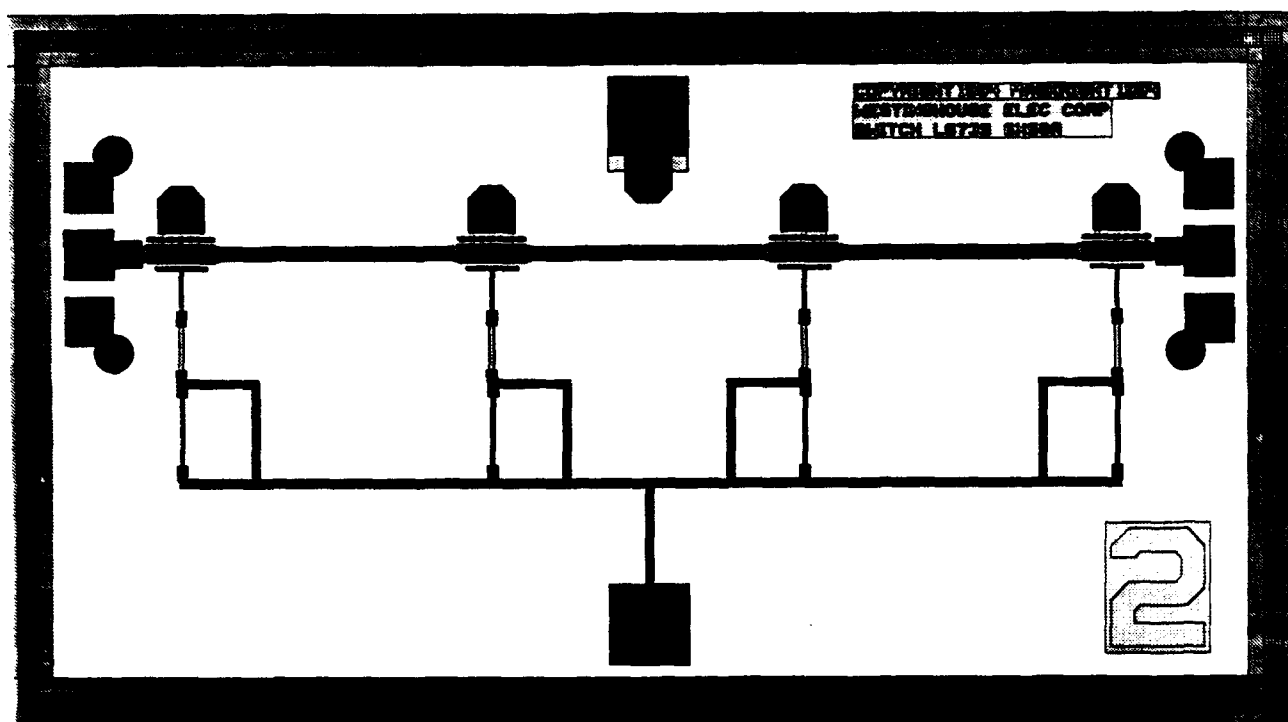
Figure 20. Layout of Device No. 2, which has conventional FETs.

33

"Normal" FET Switches at 300 K

Key: Insertion Loss (dB) @ 10 GHz
        Isolation   (dB) @ 10 GHz

Wafer 1562-1
Device 2

		0.33 / 59	0.33 / 55	0.32 / 57	0.34 / 56	
3.7 / 19.2	0.32 / 57	0.33 / 57	0.33 / 66	0.33 / 57	0.33 / 57	
0.31 / 60	0.33 / 58	0.34 / 57	0.34 / 59	0.35 / 59	0.32 / 57	0.33 / 56
0.33 / 59	0.33 / 58	0.33 / 56	0.33 / 59	0.34 / 56	0.34 / 56	
0.78 / 62	0.36 / 58	0.36 / 54	0.35 / 58	0.35 / 58	0.35 / 56	0.34 / 55
	1.27 / 54	0.36 / 56	1.95 / 56	0.33 / 55	0.65 / 56	
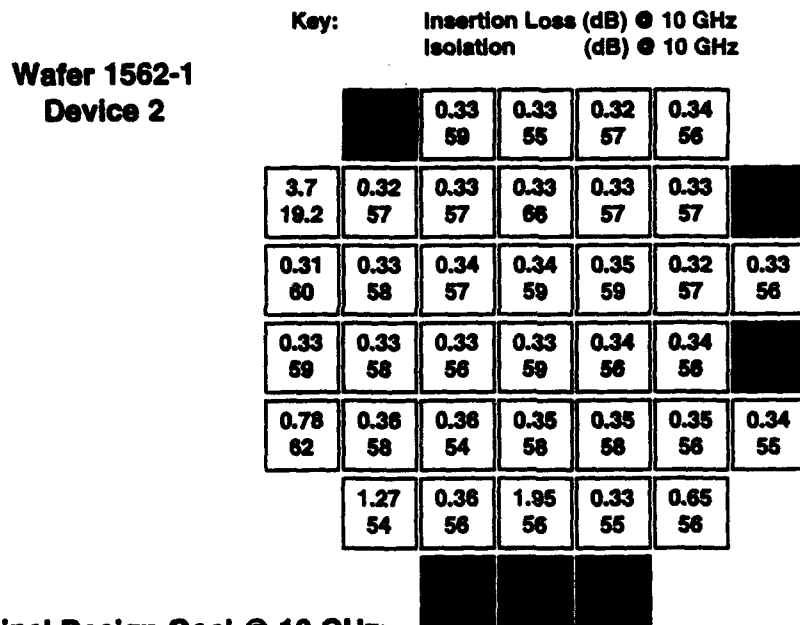
Nominal Design Goal @ 10 GHz:
Insertion Loss: 0.33 dB
Isolation: 54 dB

Westinghouse
Science and Technology Center

SHT
sb
97/94

Figure 21.   Room temperature insertion loss and isolation for Device No. 2 of wafer 1562-1 at 10 GHz showing excellent agreement with design goals.

APPENDIX

Performance Analysis of
High Temperature Superconducting
Components for ESM Systems

28 June 1994

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Background.

The future use of high temperature superconductors (HTS) that operate at liquid nitrogen temperatures (77° Kelvin) will be driven by the perceived difficulties associated with cryogenic refrigeration, the advances being made in low noise figure conventional devices, and the identified performance advantages of High Temperature Superconducting (HTS) devices. It is suspected that with time cryogenic cooling will become accepted as reliable and relatively low cost (i.e., less than $5K). In the past, radio astronomy was the major user of cooled receivers and the reason was lower noise figures and better sensitivity. ESM systems will certainly benefit in these same areas and in the increased dynamic range resulting from the reduced amplification required by HTS systems. Efforts to date to quantify these benefits have been rather piecemeal and the systems analysis has been somewhat superficial.

This report details the results of an effort to perform a more rigorous systems analysis of the benefits of using HTS components by comparing the system sensitivity and dynamic range of a typical ESM/ELINT system using the best available current technology vs. the same system using various HTS components. A two phase analysis effort was completed. The first phase modeled the insertion of several HTS devices, a Flow-through Switched Preselector Filterbank (FSP), 200 nano second Delay Lines, and an IF Filter Bank, that are currently being fabricated under contract. This effort used either measured performance results or extrapolated results to determine system level performance improvements. The second phase objective was the identification of future HTS devices that could have high performance impact.

The first step performed was to define in great detail a reference modem ESM system. This system was then optimized and analyzed using a spread sheet program referred to as ADRATS. The first ADRATS run was for optimization while the second formed the reference for HTS comparisons. The Typical ESM system is a Channelized Cued Receiver (CCR) architecture with two receiver threads of interest: a channelizer and a cued Narrow Band Receiver (NBR). Once the performance of both threads was determine, HTS devices were inserted one at a time and then in combinations. The delay line was analyzed for two different gain distributions. The ESM Analysis Summary chart is a summary of the performance improvement for various system configurations. When all HTS components were inserted and the non HTS components cooled (see Everything in the table below) the system sensitivity improved 5.1-6.1 dB and the two tone dynamic range increased 3.7-5.2 dB compared to the system using today's technology. The results below and the steps taken to obtain them are described in detail in the rest of this report.

ESM Analysis Summary

Reference

- Typical Single Site ESM System Definition
  - Architecture
  - Design Details
- ADRATS Screens Descriptions
- First ADRATS Run (Preliminary Gain)
- Gain versus Sensitivity and Two Tone Dynamic Range
- Second (2nd) ADRATS Run-Baseline
  - Channelizer Thread: Sensitivity = -72.3 dBm
    TTDR= 46.8 dB
  - NBR Thread: Sensitivity = -70.5 dBm (3rd Run: -72.1 dBm)
    TTDR =44.3 dB (3rd Run: 42.8 dB)

HTS Insertion

HTS Device(s)	Channelizer				NBR			
	Sens	Delta	TTDR	Delta	Sens	Delta	TTDR	Delta
Delay Line 1	n/a	n/a	n/a	n/a	-73.1	2.6	48.1	3.8
Delay Line 2	n/a	n/a	n/a	n/a	-72.1	0.0	50.3	7.5
Filter Bank	-72.2	-0.1	51.3	4.5	n/a	n/a	n/a	n/a
FSP vs Quads	-72.8	0.5	47.1	0.3	-70.9	0.4	44.6	0.3
FSP vs swFB	-72.8	1.9	47.1	1.3	-70.9	1.6	44.6	1.1
New FSP & SW	-77.4	6.5	46	-0.8	-75.8	5.3	43.6	-0.7
FSP, Delay, FB	-72.8	0.5	51.6	4.8	-71.6	1.1	50.4	6.1
Mixer & BPF	-71.3	-1.0	46.2	-0.6	-	-	-	-
SSB Mixer +	-73.2	0.9	47.5	0.7	-	-	-	-
Everything (All HTS or cooled)	-77.4	5.1	50.5	3.7	-76.6	6.1	49.5	5.2

ESM Receiver Architecture

Two categories of system architecture's were analyzed: ESM and a Radar/ESM Shared Aperture. ESM architecture's in use today vary widely from systems having multiple receiver types and multiple aperture sites (i.e., for 360 degrees of coverage) to simple superhet systems with a single aperture set.

The selected ESM architecture was a single site design that is believed to be typical of a modern ESM system. This design incorporates remote front-end amplification and frequency conversion to a selected IF frequency of 3 to 5 GHz. The remote IF is brought back to central via an all coax transmission system. At central a 3 to 5 GHz Channelized Cued Receiver (CCR) with 100 MHz of channelization detects, identifies, and measures angle-of-arrival (AOA) of signals-of-interest (SOI).

The CCR ESM architecture is of particular interest to the HTS analysis effort in that it will serve as a reference for measuring the performance improvements achieved through HTS insertion. HTS devices to be considered for this architecture include the currently planned HTS Filterbank, Flow-Through Switched Filters (FTSF), delay lines as well as future HTS mixers.

The Radar/ESM shared aperture architecture is similar to the CCR architecture but uses a high gain aperture that is shared by the radar. This architecture is discussed later in this report.

4
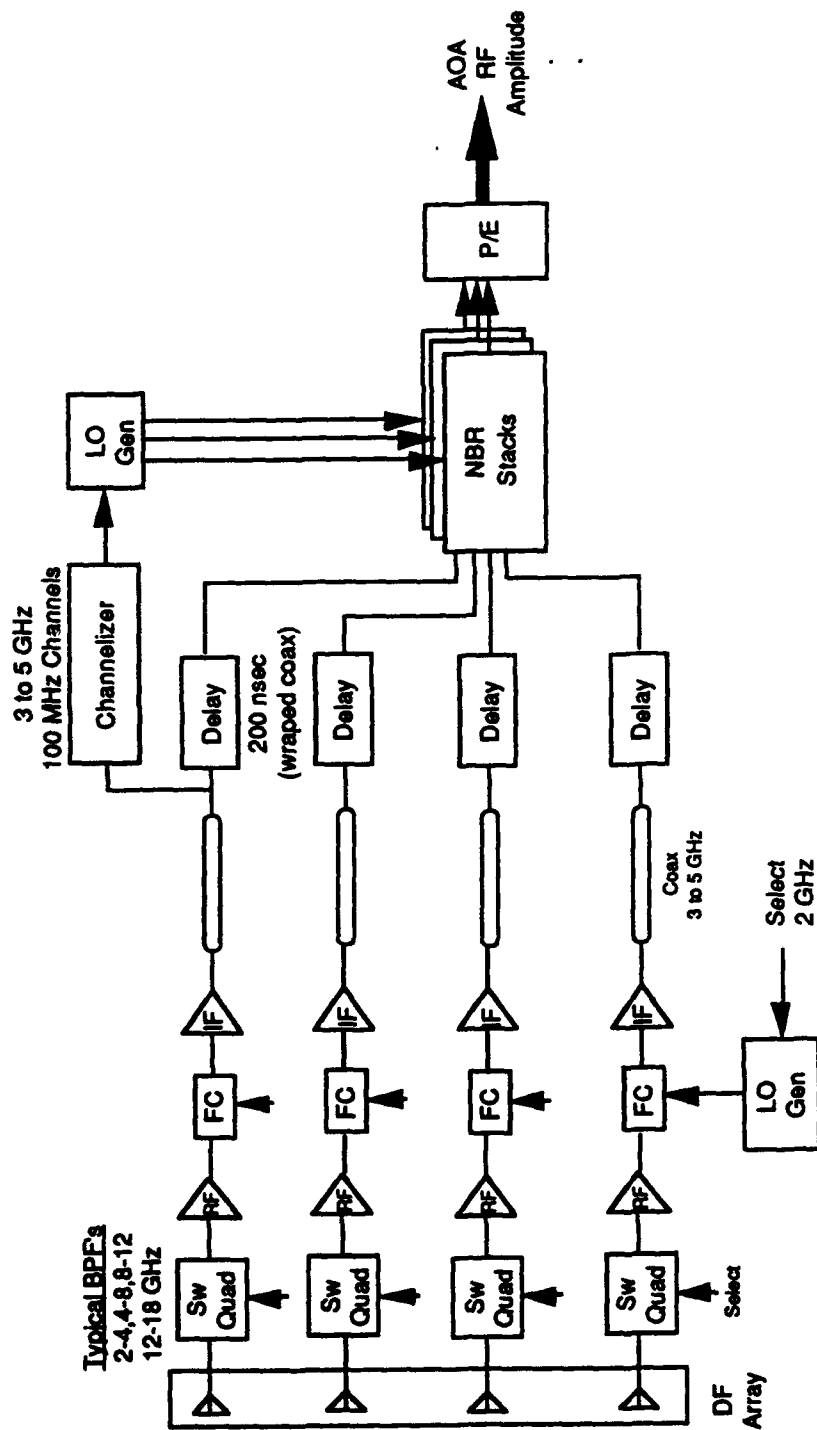
Single Site Channelizer Cued ESM Receiver

3 to 5 GHz
100 MHz Channels

Channelizer

LO Gen

NBR Stacks

P/E

AOA
RF
Amplitude

Delay
200 nsec
(wraped coax)

Delay

Delay

Delay

Coax
3 to 5 GHz

IF

IF

IF

IF

FC

FC

FC

FC

LO Gen

Select
2 GHz

RF

RF

RF

RF

Typical BPFs
2-4, 4-8, 8-12
12-18 GHz

Sw Quad

Sw Quad

Sw Quad

Sw Quad

Select

DF Array

5

Typical ESM System

A typical ESM system has a four or five element interferometer array with short phased matched cables (5 feet or less) to connect the array to the RF front-end's. The RF front-end has a Bit/Cal insertion switch at the input (couplers are also used in combination with a modulated test signal for recognition purposes). The switches are necessary for reducing channel phase and amplitude errors to maintain AOA accuracy. A quadruplexer with about 1 dB loss is used to split the RF coverage(2 to 18 GHz) into octave or less sub-bands(i.e., 2-3.5, 3.5-6, 6-10 or 2-4,4-8, 8-1`2 and 12-18 are two common selections). Note: a potential advantage of HTS is the ability to generate finer RF bandwidths without excessive loss. A finer bandwidth can prevent the generation of out-of-band spurs in the first amplifier . This can be a significant advantage but one that has no current figure-of-merit. A sp4t switch is used to select one quadruplexer output for measurement. The switch is before the RF amplifier and ,therefore, reduces sensitivity. In some applications RF amplifiers are placed at each quad output to improve sensitivity. However, these RF amplifiers are too expensive for many applications-they can cost from 3 to 5K dollars each.

Remote frequency conversion is used in many platforms to avoid use of wave guide or excessive transmission loss. It also improves sensitivity slightly by reducing gain and power output requirements in the RF amplifier and placing much of the gain within a lower NF IF amplifier. The IF selected is driven by a number of factors with 3 to 5 GHz being typical (6-10 GHz, 0.75 to 1.25 GHz, and 130-190 MHz being other IF's).

The IF delay lines of the CCR are wrapped 141 coax broken into 100 nsec increments. Amplifiers are placed between segments to make the total gain equal to unity. The typical IF delay line is a major source of system noise and impacts both receiver sensitivity and dynamic range. It is certainly a candidate for improvement.

The channelizer incorporates a lumped element filter bank with a loss of about 15 dB. Channelizer filter bank losses have been seen with losses that range from 12 to nearly 40 dB. The selected lumped element filter bank provides 3 to 5 GHz of coverage with 100 MHz of channelization. Note: an advantage of an HTS filter bank is a higher Q than lumped element that permits the desired 50 MHz channelization to be obtained.

6

Typical ESM System

7
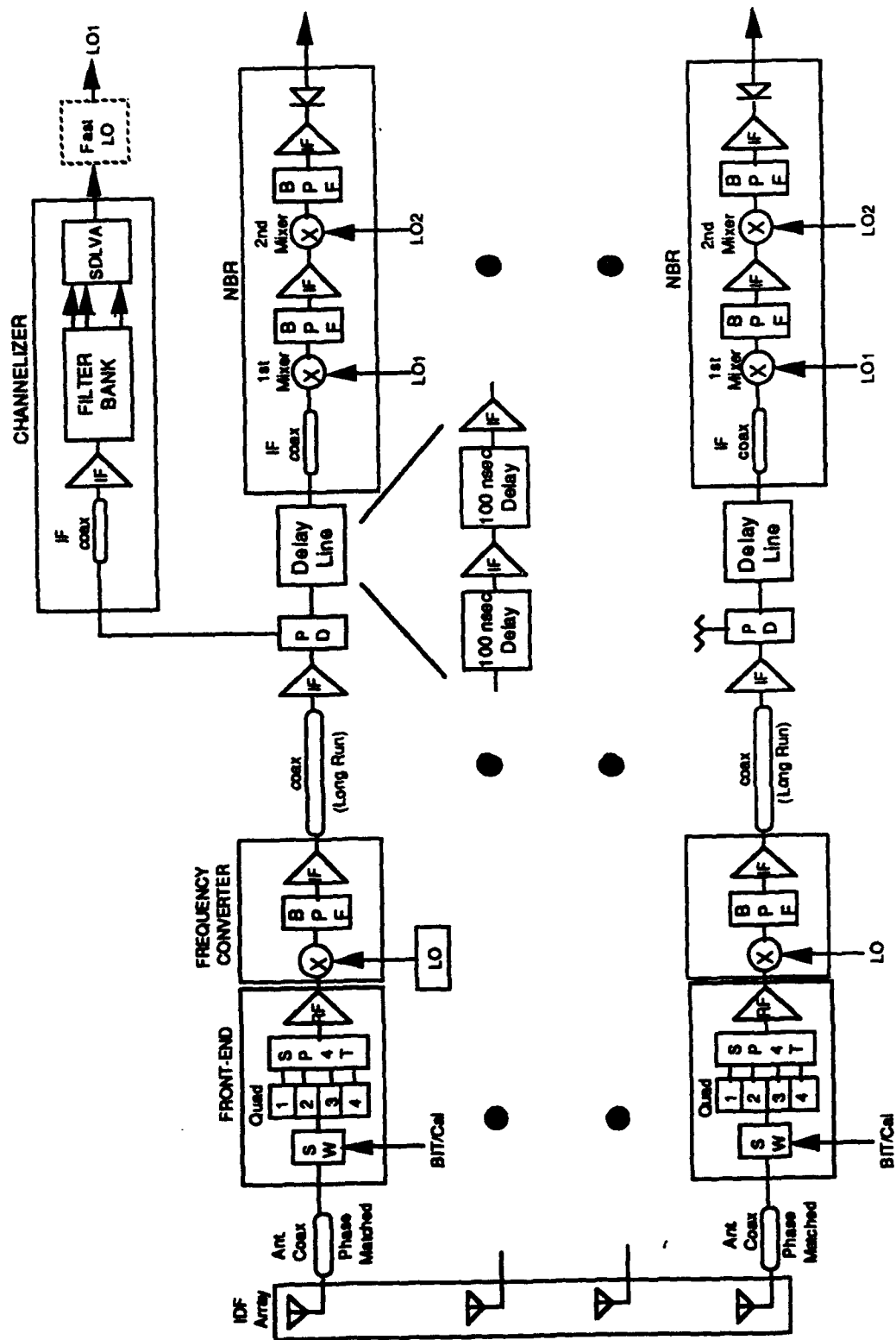
ESM - First Run

The Typical ESM System is important in that it is the reference used in determining the performance advantages of HTS insertion. The procedure used was as follows. First, a preliminary estimate of all hardware used in the Typical ESM System was made and ADRATS was used to analyze it's performance (this is the ESM - First Run print-out). This run was used as a baseline to determine the optimum gain distribution within the architecture. The amplifier gains and components were then fixed for the Typical ESM System and the performance re-analyzed using ADRATS. Finally, various HTS options were inserted into the system and new analysis runs made.

Several things should be noted concerning the ADRATS print outs. First, it should be noted that the indicated Front-End values for gain(10), NF(8) and IP3(25) are determined by the components listed below Front-End (the last RF AMPL values are the 10,8, and 25 values). Secondly it should be noted that in ADRATS a divider is a loss less splitter that creates two paths.

DATE:04-06-1994   TIME=08:24:20

NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
2. FRONT-END	10.0	8.0	25.0	9.0	9.0	25.0	-96.0	n/a	n/a
-BIT SWITCH	-1.5	1.5	40.0	-1.5	1.5	40.0	-114.0	n/a	n/a
-QUADPLXR	-1.0	1.0	99.0	-2.5	2.5	39.0	-114.0	n/a	n/a
-SP4T	-2.5	2.5	40.0	-5.0	5.0	34.9	-114.0	n/a	n/a
-RF AMPL	15.0	3.0	25.0	10.0	8.0	25.0	-96.0	n/a	n/a
3. FREQ CONV	7.0	11.0	26.5	16.0	9.7	25.4	-88.3	n/a	n/a
-MIXER	-7.0	7.0	15.0	-7.0	7.0	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-8.0	8.0	14.0	-114.0	n/a	n/a
-IF AMPL	15.0	3.0	30.0	7.0	11.0	26.5	-96.0	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	6.0	9.8	15.4	-98.2	n/a	n/a
5. IF AMP	15.0	3.0	30.0	21.0	9.9	27.2	-83.1	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	17.5	10.0	23.7	-86.5	n/a	n/a
7. Divider	n/a	n/a	n/a	17.5	10.0	23.7	n/a	n/a	n/a
8. CHANNELZR	3.5	5.1	15.0	21.0	10.0	14.7	-83.0	44.8	-73.4
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF CABLE	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-AMPLIFIER	20.0	3.0	30.0	18.5	4.5	30.0	-91.0	n/a	n/a
-FILTERBNK	-15.0	15.0	99.0	3.5	5.1	15.0	-105.4	n/a	n/a
-SDLVA	0.0	0.0	99.0	3.5	5.1	15.0	-105.4	49.3	-62.4
9. DELAY LINE	0.0	23.0	27.0	17.5	11.3	22.0	-85.2	n/a	n/a
-100 NSEC	-17.0	17.0	99.0	-17.0	17.0	99.0	-114.0	n/a	n/a
-1ST AMP	17.0	3.0	30.0	0.0	20.0	30.0	-94.0	n/a	n/a
-100 NSEC	-17.0	17.0	99.0	-17.0	21.7	13.0	-109.3	n/a	n/a
-2ND AMP	17.0	3.0	30.0	0.0	23.0	27.0	-91.0	n/a	n/a
10. NB RCVR	4.5	16.5	22.0	22.0	11.5	20.7	-80.5	47.1	-72.0
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF COAX	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-1ST MIXER	-7.0	7.0	15.0	-8.5	8.5	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-9.5	9.5	14.0	-114.0	n/a	n/a
-1ST IF	11.0	5.3	30.0	1.5	14.8	23.8	-97.7	n/a	n/a
-2ND MIXER	-7.0	7.0	15.0	-5.5	15.2	12.8	-104.3	n/a	n/a
-BPF	-1.0	1.0	99.0	-6.5	15.3	11.8	-105.2	n/a	n/a
-2ND IF	11.0	5.3	30.0	4.5	16.5	22.0	-93.0	n/a	n/a
-DLVA	0.0	0.0	99.0	4.5	16.5	22.0	-93.0	53.4	-62.6

ADRATS

ADRATS provides a hierarchical description of a system using boxes (Gain, Coax, Divider, and Receiver). The first level shows the entire system defined in terms of these boxes. Any box exhibiting a "**" at the bottom contains parameter values that were calculated at a higher level screen (this will become apparent in following screens). Boxes with the "**" include the front-end, channelizer, delay line and NB Rcvr boxes. Each box is also number and later plots will be shown reflecting parameter values as a function of these box numbers. The boxes shown in the screen were initially generated by selecting the box type from the selector boxes shown on the right of the screen and then inserting the appropriate data into the box. ADRATS then computes gain, NF, IP3, sensitivity, dynamic range and other requested parameters based on these entries. Again it should be noted that box 7 is a loss less divider whose only function is to form two paths (for the two receivers). In latter analysis the divider will be removed and each path or thread (Channelizer and NBR) will be analyzed separately.

ADRATS displays this same information by way of brightly colored boxes. To illustrate, a screen grabber was used to copy and print the screens associated with the First Run is shown below. Each different run had a similar format.

10

RF Gain

Coax

Divider

Insert

Back

[ANT CABLE]
Loss= 1.0dB
1

[FRONT-END]
Gain= 10.0dB
NF = 8.0dB
IP3= 25.0dBm
2

[FREQ CONV]
Gain= 7.0dB
NF = 11.0dB
IP3= 26.5dBm
3

[LONG RUN]
Loss=15.0dB
4

[IF AMP]
Gain= 15.0dB
NF = 3.0dB
IP3= 30.0dBm
5

[PWR SPLIT]
Gain= -3.5dB
NF = 3.5dB
IP3= 99.0dBm
6

Divider
7

[CHANNEL2R]
Tss=-65.0dBm
Gain= 3.5dB
NF = 5.1dB
8

[DELAY LINE]
Gain= 0.0dB
NF = 23.0dB
IP3= 27.0dBm
9

[NB RCVR]
Tss=-65.0dBm
Gain= 4.5dB
NF= 16.5dB
10

Typical ESM System

Front-End

The selected front-end is comprised of four blocks: a SP2T BIT/Cal switch, a quadruplexer filter separator, a SP4T filter selector switch and a wide-band RF amplifier as shown in the ADRATS screen print out below. The total noise figure of these components is 8 dB of which 5 dB represents the loss of the components in front of the amplifier.

The BIT/Cal switch at the input allows insertion of an RF signal for fault isolation and calibration purposes. The switch is the first component in the string and therefore, must be relatively high power and must have high isolation to prevent outside signals from interfering with the test process. The quadruplexer serves to separate the 2 to 18 GHz range into sub-bands with octave or less bandwidths. These suspended substrate devices exhibit a loss of only 1 dB. In most ESM applications sensitivity is important and any loss in the front-end prior to the amplifier subtracts from sensitivity. In some applications sensitivity is so important that amplifiers are placed at each quadruplexer output prior to switching. This significantly increases cost but does improve sensitivity by effectively eliminating the switch loss (about 2.5 dB). In other applications, emitter density is the major design driver and finer RF filtering than that provided by the simple quadruplexer is desired. The multiple channel switched filter bank by Eastern Multiplexers, Inc can provide up to 13 filter channels over the 2 to 18 GHz band with a total loss of 6 dB. Ideally, the front end preselection filter bandwidths should match the IF bandwidth to prevent spurs.

The Front End block of the ADRATS simulation is shown in an expanded format below.

12

RF Gain

Coax

Divider

Rcvr

Back

Lock

[RF AMPL]
Gain= 15.0dB
NF = 3.0dB
IP3= 25.0dBm
4

[SP4T]
Gain= -2.5dB
NF = 2.5dB
IP3= 40.0dBm
3

[QUADPLXR]
Gain= -1.0dB
NF = 1.0dB
IP3= 99.0dBm
2

[BIT SWITCH]
Gain= -1.5dB
NF = 1.5dB
IP3= 40.0dBm
1

Help(F1)   Copyright(c): 1993 Willmore Video   Menu(ALT-M)   L 2
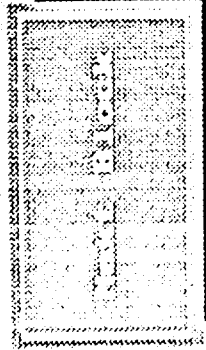
Frequency Converter

The Frequency Converter is comprised of three blocks: a mixer, a bandpass filter, and an IF amplifier. The mixer selected has a 7 dB conversion loss and an output IP3 of 15 dBm. The relatively high IP3 implies that this is a high power mixer requiring an LO power on the order of 20 dBm. The IF amplifier is a relatively low gain amplifier with a good noise figure. The IP3 of the amplifier is 30 dBm implying that the amplifier 1 dB power output is about 20 dBm. A slightly higher power amplifier is desired but would increase the noise figure of the system and decrease its sensitivity..

The expanded version of the Frequency Converter box is shown below in the ADRATS format.

14

RF Gain
↑

Coax
█

Divider
▲ 2
[+]
▲ 2

Rcvr
↓

Back

Lock

[FREQ CONV]

[MIXER   ]
Gain= -7.0dB
NF = 7.0dB
IP3= 15.0dBm
1

[BPF   ]
Gain= -1.0dB
NF = 1.0dB
IP3= 99.0dBm
2

[IF AMPL   ]
Gain= 15.0dB
NF = 3.0dB
IP3= 30.0dBm
3

Next Block

Frequency Converter

USER MENU

Coax

Gain: -7.8dB
dB: 2.0dB
NF: 5.01dB
1

Gain: -1.1dB
dB: 1.0dB
NF: 55.01dB
2

Gain: 15.0dB
dB: 3.0dB
NF: 55.01dB
3

Back

Lock

Frequency Converter

Channelizer Thread

Channelizer Thread

Back

Lock

Conx

Help(F1)

RF Gain

Coax

Divider

Rcvr

Back

Lock

[100 NSEC]
Gain=-17.0dB
NF = 17.0dB
IP3= 99.0dBm
1

[1ST AMP]
Gain= 17.0dB
NF = 3.0dB
IP3= 30.0dBm
2

[100 NSEC]
Gain=-17.0dB
NF = 17.0dB
IP3= 99.0dBm
3

[2ND AMP]
Gain= 17.0dB
NF = 3.0dB
IP3= 30.0dBm
4

Next Block

Help(F1)   Copyright(c): 1993 Willmore Video   Menu(ALT-M)   L 6

Delay Line

Narrow Band Receiver (NBR) Thread

RF Gain
Coax
Divider
Flour
Back
Lock

[1ST IF]
Gain= 11.0dB
NF = 5.3dB
IP3= 30.0dBm
4

[LOLA]
Tss=-65.0dBm
Gain= 0.0dB
NF= 0.0dB
8

[LPF]
Gain= -1.0dB
NF = 1.0dB
IP3= 99.0dBm
3

[2ND IF]
Gain= 11.0dB
NF = 5.3dB
IP3= 30.0dBm
7

[1ST MIXER]
Gain= -7.0dB
NF = 7.0dB
IP3= 15.0dBm
2

[LPF]
Gain= -1.0dB
NF = 1.0dB
IP3= 99.0dBm
6

[2ND MIXER]
Gain= -7.0dB
NF = 7.0dB
IP3= 15.0dBm
5

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Narrow Band Receiver (NBR) Thread

Sensitivity vs Gain

NF = 5 dB

10 dB

15 dB

Brf = 100 MHz

Bv = 20 Mhz

SNR= 14 dB

Tssd=-65 dBm

Electronic Gain(dB)
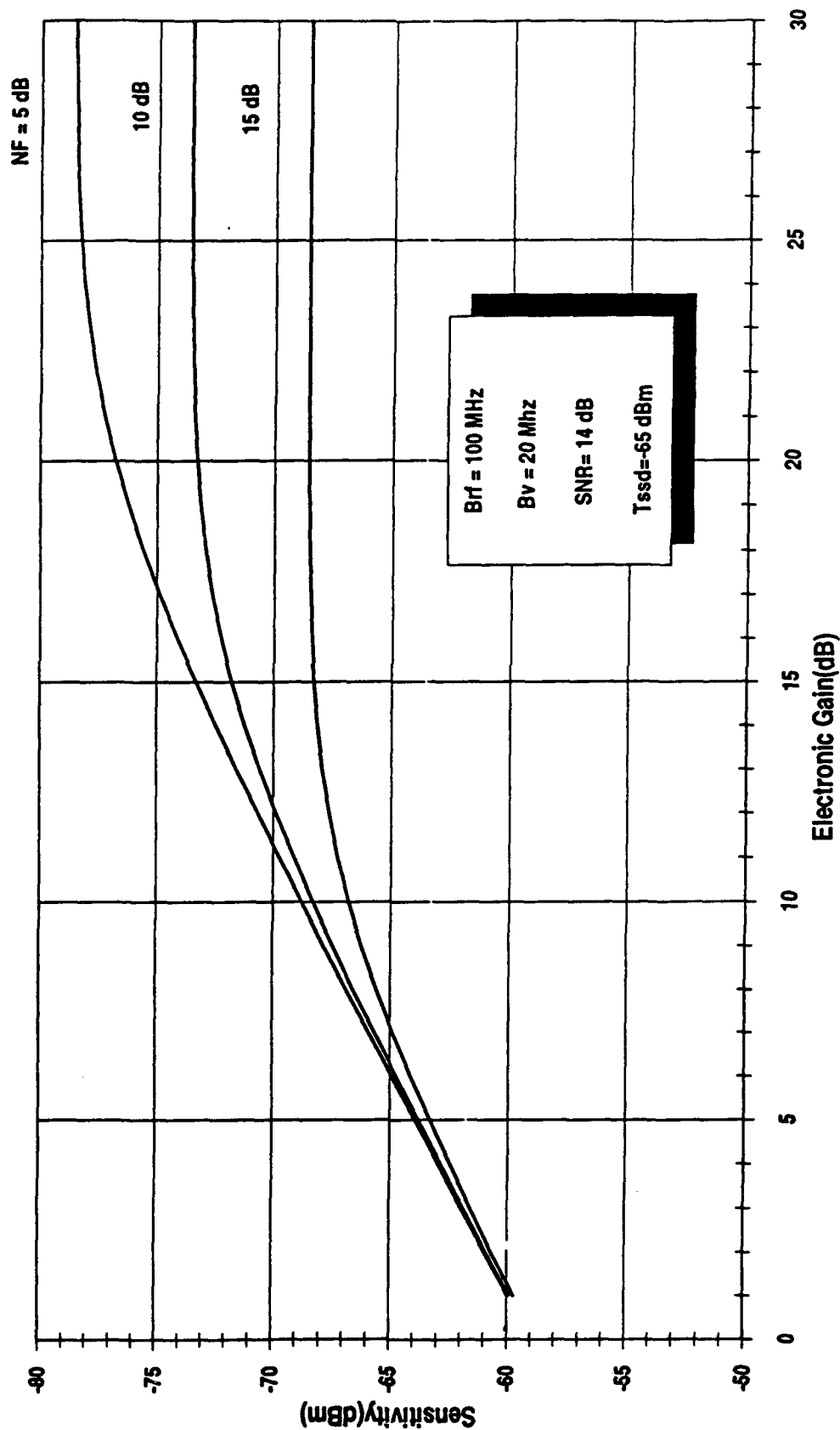
Sensitivity(dBm)

Sensitivity Gain Limit

In almost all applications it is desirable to operate with or near maximum sensitivity. Any RF gain greater than 14 dB is seen to produce a sensitivity that is within 3 dB of the maximum or saturation sensitivity value. However, it is equally true that instantaneous dynamic range is important and too high a gain will cause a loss in dynamic range.

24

Sensitivity vs Gain

NF   = 10.5
SNR   = 14
BWRF = 100
BWv   = 20

> 14 dB

Gain(dB)
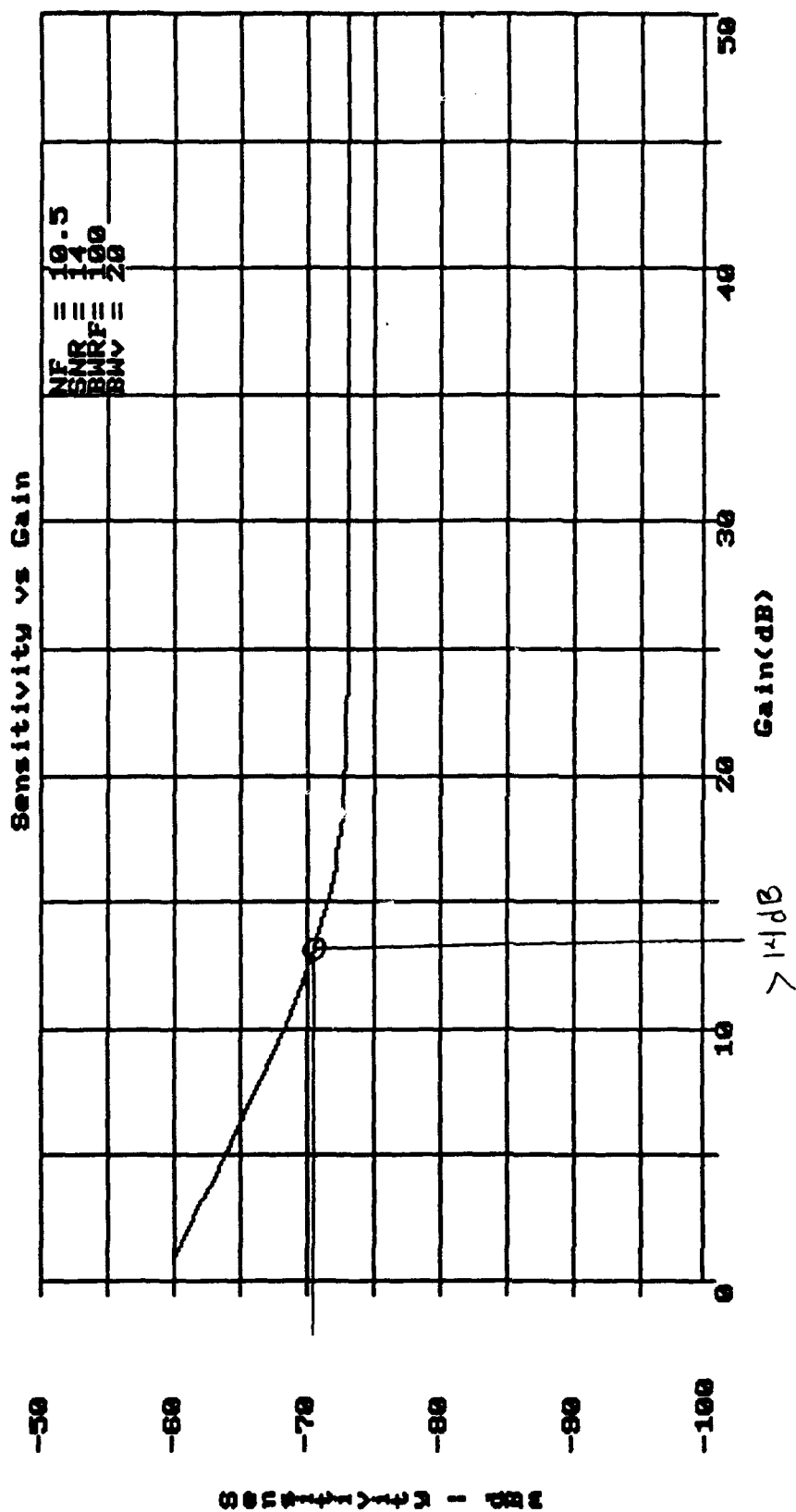
dB - Sensitivity

Dynamic Range Gain Limit

The First Run results indicated a total or effective IP3 relative to the output of 14.7 dBm. The instantaneous Two Tone Dynamic Range is computed as follows:

$$TTDR = 2/3[(IP3-Gain) - Sensitivity].$$

At low RF gains the sensitivity has been seen to increase linearly with gain. Similarly, the IP3 reflected to the input decreases linearly with RF gain. The result is that TTDR remains flat with gain until the gain increases causes front-end noise to begin controlling output noise and sensitivity. TTDR then begins to fall linearly 6.66 dB for every 10 dB increase in gain. In order to achieve within 3 dB of maximum TTDR the gain should be less than 18 dB. The RF gain of the channelizer path is now limited

Two Tone Dynamic Range vs Gain

```
NF    = 10.5
SNR   = 140
BWRf  = 100
BWx   = 20
IP3   = 15
```


Gain(dB)
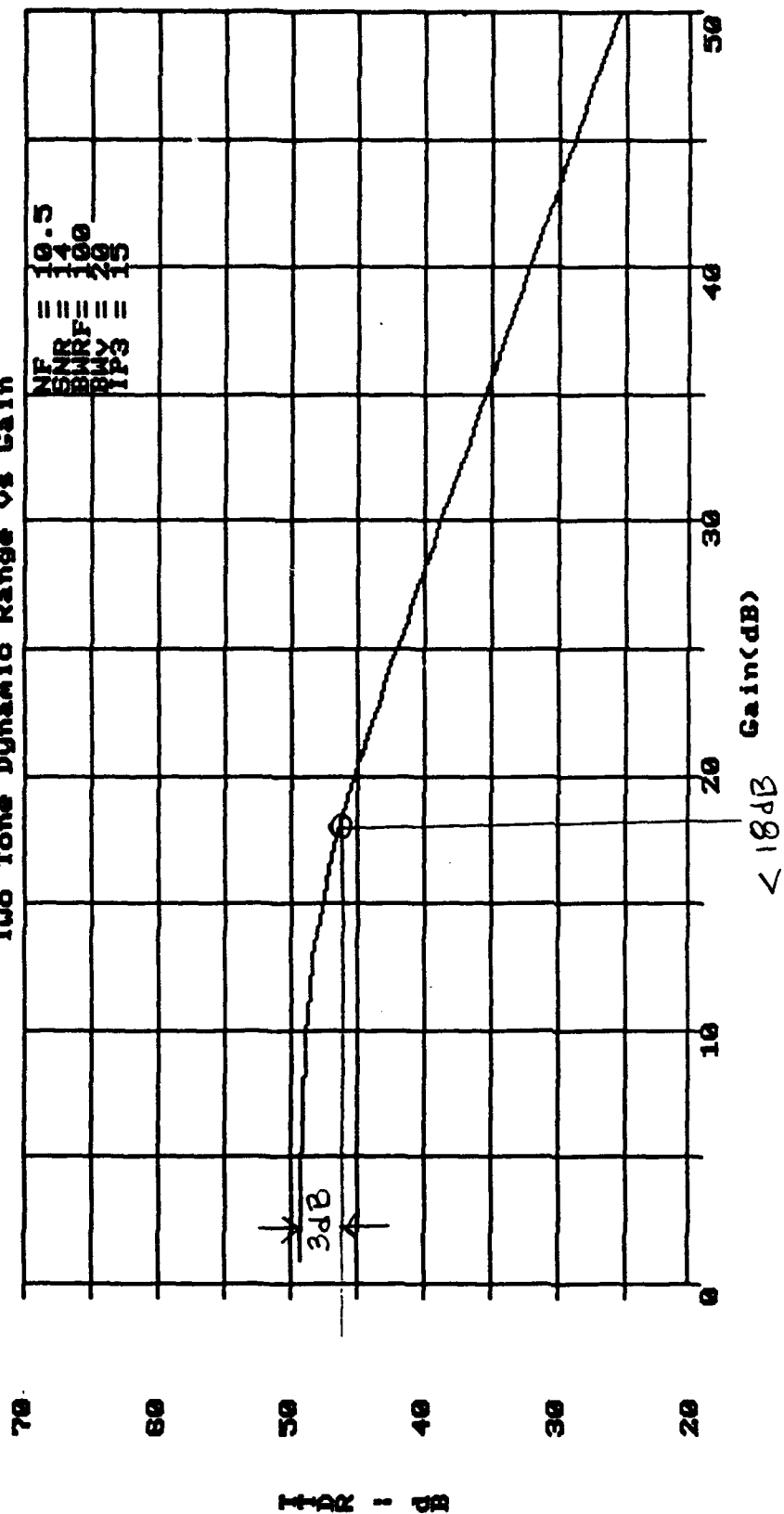
ESM - 2nd Run

The Channelizer path has gain limits of above 14 dB and below 18 dB (the 2nd Run data shows that 16 dB is now set). However, the NBR thread is made more complex by the inclusion of the 200 nsec delay line with an equivalent noise figure of over 30 dB. This noise figure is so large that it takes a large gain to make front-end gain predominate. The net result is lower TTDR. One approach previously used for these conditions is to set the front-end noise equal to the back-end noise driver. This is the approach of the 2nd Run as evident by the 3 dB noise figure increase associated with the delay line from about 10 to 13 dB). The second approach that has been previously used to set gains is to continue to increase front-end gain until sensitivity begins to saturate. This approach, as will be seen in 3rd Run to follow, would result in a 1.6 dB higher sensitivity and a 1.5 dB reduction in TTDR. Both approaches will be used to measure the performance enhancements of HTS insertion.

ESM - 2ND RUN

DATE:04-06-1994   TIME=12:25:01

NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
2. FRONT-END	10.0	8.0	25.0	9.0	9.0	25.0	-96.0	n/a	n/a
-BIT SWITCH	-1.5	1.5	40.0	-1.5	1.5	40.0	-114.0	n/a	n/a
-QUADPLXR	-1.0	1.0	99.0	-2.5	2.5	39.0	-114.0	n/a	n/a
-SP4T	-2.5	2.5	40.0	-5.0	5.0	34.9	-114.0	n/a	n/a
-RF AMPL	15.0	3.0	25.0	10.0	8.0	25.0	-96.0	n/a	n/a
3. FREQ CONV	7.0	11.0	26.5	16.0	9.7	25.4	-88.3	n/a	n/a
-MIXER	-7.0	7.0	15.0	-7.0	7.0	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-8.0	8.0	14.0	-114.0	n/a	n/a
-IF AMPL	15.0	3.0	30.0	7.0	11.0	26.5	-96.0	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	6.0	9.8	15.4	-98.2	n/a	n/a
5. IF AMP	18.0	3.0	30.0	24.0	9.9	28.4	-80.1	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	20.5	9.9	24.9	-83.6	n/a	n/a
7. Divider	n/a	n/a	n/a	20.5	9.9	24.9	n/a	n/a	n/a
8. CHANNELZR	-4.5	7.4	15.0	16.0	10.0	13.9	-88.0	46.8	-72.3
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF CABLE	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-AMPLIFIER	12.0	3.0	30.0	10.5	4.5	30.0	-99.0	n/a	n/a
-FILTERBNK	-15.0	15.0	99.0	-4.5	7.4	15.0	-111.1	n/a	n/a
-SDLVA	0.0	0.0	99.0	-4.5	7.4	15.0	-111.1	49.3	-54.5
9. DELAY LINE	0.0	30.5	27.0	20.5	13.0	22.8	-80.5	n/a	n/a
-100 NSEC	-25.0	25.0	99.0	-25.0	25.0	99.0	-114.0	n/a	n/a
-1ST AMP	25.0	2.5	30.0	0.0	27.5	30.0	-86.5	n/a	n/a
-100 NSEC	-25.0	25.0	99.0	-25.0	29.4	5.0	-109.6	n/a	n/a
-2ND AMP	25.0	2.5	30.0	0.0	30.5	27.0	-83.5	n/a	n/a
10. NB RCVR	4.5	16.5	22.0	25.0	13.1	20.9	-75.9	44.3	-70.5
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF COAX	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-1ST MIXER	-7.0	7.0	15.0	-8.5	8.5	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-9.5	9.5	14.0	-114.0	n/a	n/a
-1ST IF	11.0	5.3	30.0	1.5	14.8	23.8	-97.7	n/a	n/a
-2ND MIXER	-7.0	7.0	15.0	-5.5	15.2	12.8	-104.3	n/a	n/a
-BPF	-1.0	1.0	99.0	-6.5	15.3	11.8	-105.2	n/a	n/a
-2ND IF	11.0	5.3	30.0	4.5	16.5	22.0	-93.0	n/a	n/a
-DLVA	0.0	0.0	99.0	4.5	16.5	22.0	-93.0	53.4	-62.6

ESM2ND.RFH

ESM - 3rd Run

The 3rd Run is based on increasing RF gain in front of the delay line until the NBR sensitivity begins to saturate. This occurs at a total gain in the NBR path of 29 dB or 13 dB higher than the channelizer path. The net result is a sensitivity that is 1.6 dB higher than that of the 2nd Run combined with a 1.5 dB lower TTDR. The gain of the channelizer path has been redistributed to reflect the higher NBR thread gain achieved without adding an additional amplifier. The impact on the channelizer thread is no change in sensitivity but a 0.6 dB loss in dynamic range. Again, both the 2nd Run and the 3rd Run results will be used to measure HTS insertion changes. However, most of the following discussions will concentrate on the 2nd Run results.

30

DATE:04-13-1994   TIME=10:27:00

NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
2. FRONT-END	10.0	8.0	25.0	9.0	9.0	25.0	-96.0	n/a	n/a
-BIT SWITCH	-1.5	1.5	40.0	-1.5	1.5	40.0	-114.0	n/a	n/a
-QUADPLXR	-1.0	1.0	99.0	-2.5	2.5	39.0	-114.0	n/a	n/a
-SP4T	-2.5	2.5	40.0	-5.0	5.0	34.9	-114.0	n/a	n/a
-RF AMPL	15.0	3.0	25.0	10.0	8.0	25.0	-96.0	n/a	n/a
3. FREQ CONV	7.0	11.0	26.5	16.0	9.7	25.4	-88.3	n/a	n/a
-MIXER	-7.0	7.0	15.0	-7.0	7.0	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-8.0	8.0	14.0	-114.0	n/a	n/a
-IF AMPL	15.0	3.0	30.0	7.0	11.0	26.5	-96.0	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	6.0	9.8	15.4	-98.2	n/a	n/a
5. IF AMP	22.0	3.0	30.0	28.0	9.9	29.3	-76.1	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	24.5	9.9	25.8	-79.6	n/a	n/a
7. Divider	n/a	n/a	n/a	24.5	9.9	25.8	n/a	n/a	n/a
8. CHANNELZR	-8.5	10.2	15.0	16.0	10.0	13.0	-88.0	46.2	-72.3
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF CABLE	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-AMPLIFIER	8.0	4.0	30.0	6.5	5.5	30.0	-102.0	n/a	n/a
-FILTERBNK	-15.0	15.0	99.0	-8.5	10.2	15.0	-112.3	n/a	n/a
-SDLVA	0.0	0.0	99.0	-8.5	10.2	15.0	-112.3	49.3	-50.5
9. DELAY LINE	0.0	30.5	27.0	24.5	11.4	23.3	-78.1	n/a	n/a
-100 NSEC	-25.0	25.0	99.0	-25.0	25.0	99.0	-114.0	n/a	n/a
-1ST AMP	25.0	2.5	30.0	0.0	27.5	30.0	-86.5	n/a	n/a
-100 NSEC	-25.0	25.0	99.0	-25.0	29.4	5.0	-109.6	n/a	n/a
-2ND AMP	25.0	2.5	30.0	0.0	30.5	27.0	-83.5	n/a	n/a
10. NB RCVR	4.5	16.5	22.0	29.0	11.5	21.0	-73.5	42.8	-72.1
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF COAX	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-1ST MIXER	-7.0	7.0	15.0	-8.5	8.5	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-9.5	9.5	14.0	-114.0	n/a	n/a
-1ST IF	11.0	5.3	30.0	1.5	14.8	23.8	-97.7	n/a	n/a
-2ND MIXER	-7.0	7.0	15.0	-5.5	15.2	12.8	-104.3	n/a	n/a
-BPF	-1.0	1.0	99.0	-6.5	15.3	11.8	-105.2	n/a	n/a
-2ND IF	11.0	5.3	30.0	4.5	16.5	22.0	-93.0	n/a	n/a
-DLVA	0.0	0.0	99.0	4.5	16.5	22.0	-93.0	53.4	-62.6

ESM3RD.RFH

ESM - Channelizer Thread

The ESM - 2nd Run has two receiver paths or threads: Channelizer and NBR. It is easier to analyze these threads with ADRATS when they are separate. A comparison of the ESM - 2nd Run data and the Channelizer thread data shows that they are both the same (Gain of 16 dB, sensitivity of -72.3 dBm and a TTDR of 46.8 dB). One of the advantages of a single thread is that ADRATS can then plot the change in parameter value with block or box number. This can very valuable in determining what box is driving a given parameter. The following plots illustrate the change in Channelizer thread Gain, NF, and IP3 with box number.

ESM - CHANNELIZER THREAD

NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
2. FRONT-END	10.0	8.0	25.0	9.0	9.0	25.0	-96.0	n/a	n/a
-BIT SWITCH	-1.5	1.5	40.0	-1.5	1.5	40.0	-114.0	n/a	n/a
-QUADPLXR	-1.0	1.0	99.0	-2.5	2.5	39.0	-114.0	n/a	n/a
-SP4T	-2.5	2.5	40.0	-5.0	5.0	34.9	-114.0	n/a	n/a
-RF AMPL	15.0	3.0	25.0	10.0	8.0	25.0	-96.0	n/a	n/a
3. FREQ CONV	7.0	11.0	26.5	16.0	9.7	25.4	-88.3	n/a	n/a
-MIXER	-7.0	7.0	15.0	-7.0	7.0	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-8.0	8.0	14.0	-114.0	n/a	n/a
-IF AMPL	15.0	3.0	30.0	7.0	11.0	26.5	-96.0	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	6.0	9.8	15.4	-98.2	n/a	n/a
5. IF AMP	18.0	3.0	30.0	24.0	9.9	28.4	-80.1	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	20.5	9.9	24.9	-83.6	n/a	n/a
7. CHANNELZR	-4.5	7.4	15.0	16.0	10.0	13.9	-88.0	46.8	-72.3
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-Coax	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-AMPLIFIER	12.0	3.0	30.0	10.5	4.5	30.0	-99.0	n/a	n/a
-FILTERBNK	-15.0	15.0	99.0	-4.5	7.4	15.0	-111.1	n/a	n/a
-SDLVA	0.0	0.0	99.0	-4.5	7.4	15.0	-111.1	49.3	-54.5

ESMCH.RFH

Channelizer Thread - Gain

A goal is to have gain build up in the front-end and always maintain a positive gain thereafter of about 10 dB. This would generally ensure that the *front-end* is in control of sensitivity. In the Channelizer thread the gain is seen to build to 16 db in the front-end and then fall due to coax loss to 6 dB before buiding up to the final value of 16 dB.

Gain(dB)

SNR == 14
BWRf == 100
BWV == 20

BOX NUMBER

50

38

28

17

6

-5

G
a
i
n
-
d
B

11

9

7

5

3

1
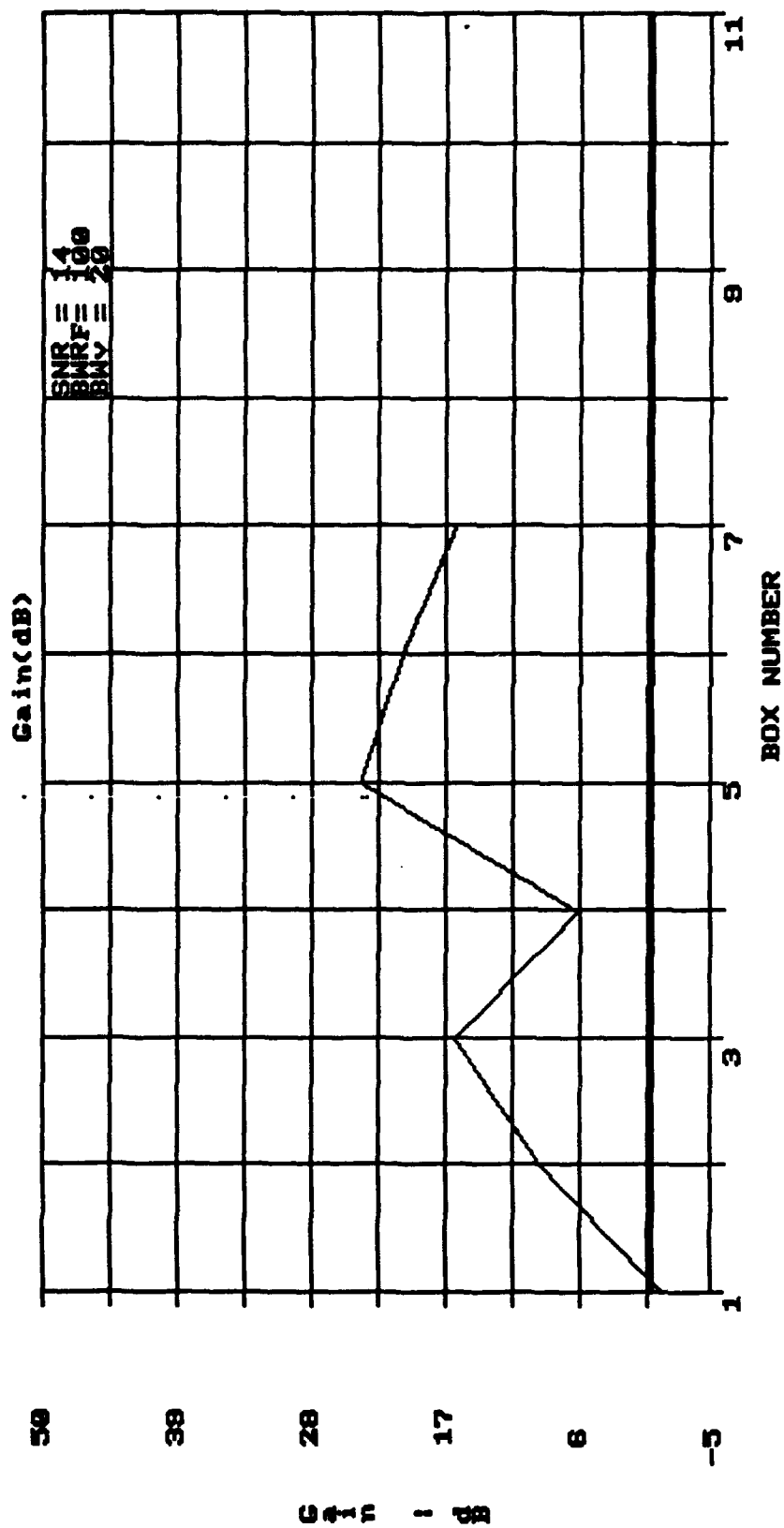
Gain - Channelizer Tower(s)

Channelizer Thread - Noise Figure

The goal is to have the total or equivalent noise figure to be set and controlled by the front-end. In the Channelizer thread the NF reaches 9 dB after front-end amplification and reaches only 10 dB at the end of the string.
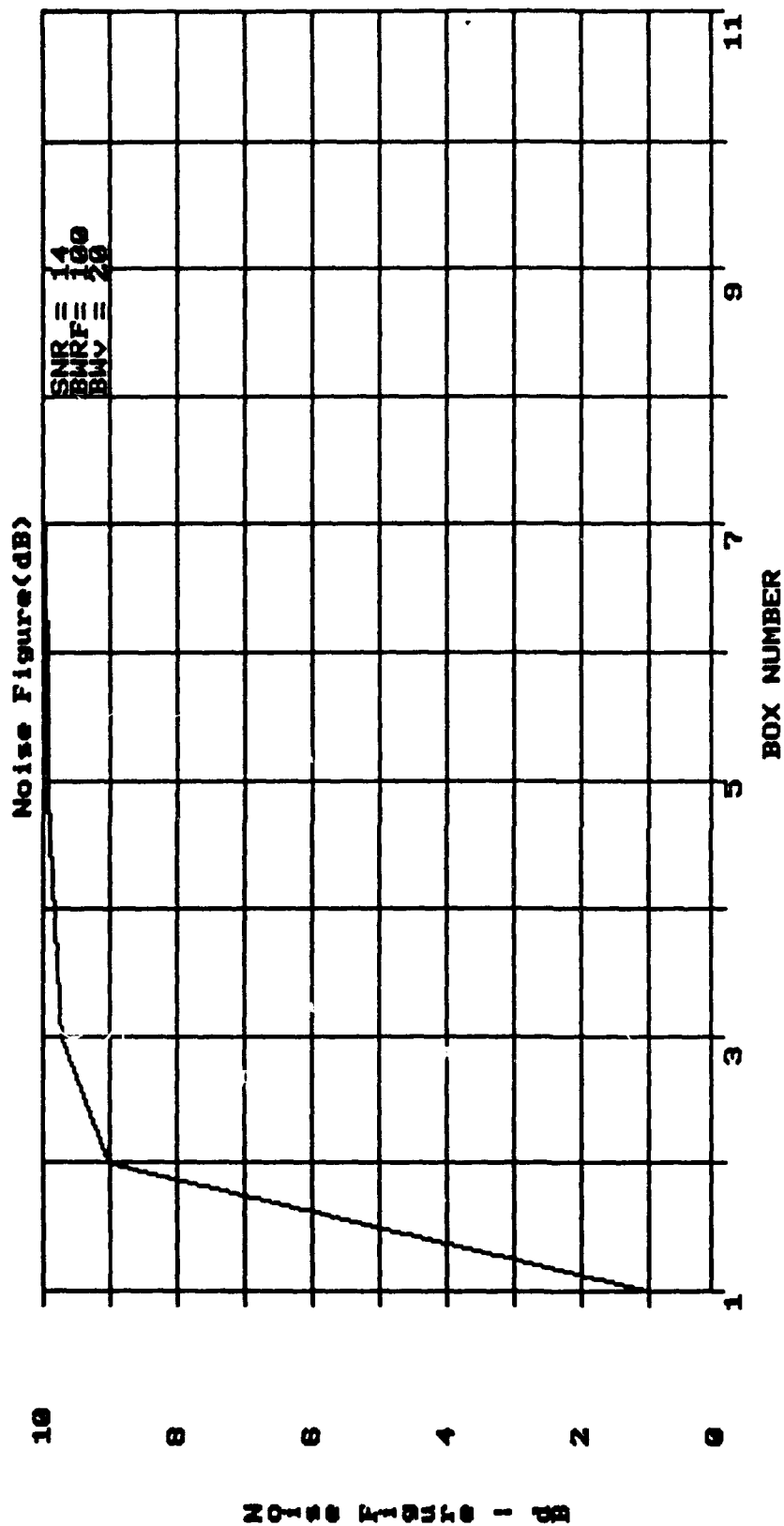
NF- Channelizer Threat

Channelizer Thread - IP3

The goal is to have the IP3 reflected to the input to be set and fall rapidly with the front-end and then remain rather flat indicating that back-end components are not greatly impacting IP3 and TTDR. However, in the Channelizer thread box 7 or the channelizer is seen to have some impact on IP3. This impact is due to the relatively high filter bank loss of 15 dB that was made up for by adding an additional amplifier with a finite IP3.

IP3 in dBm

SNR = 14
BWRF = 100
BWV = 20

BOX NUMBER
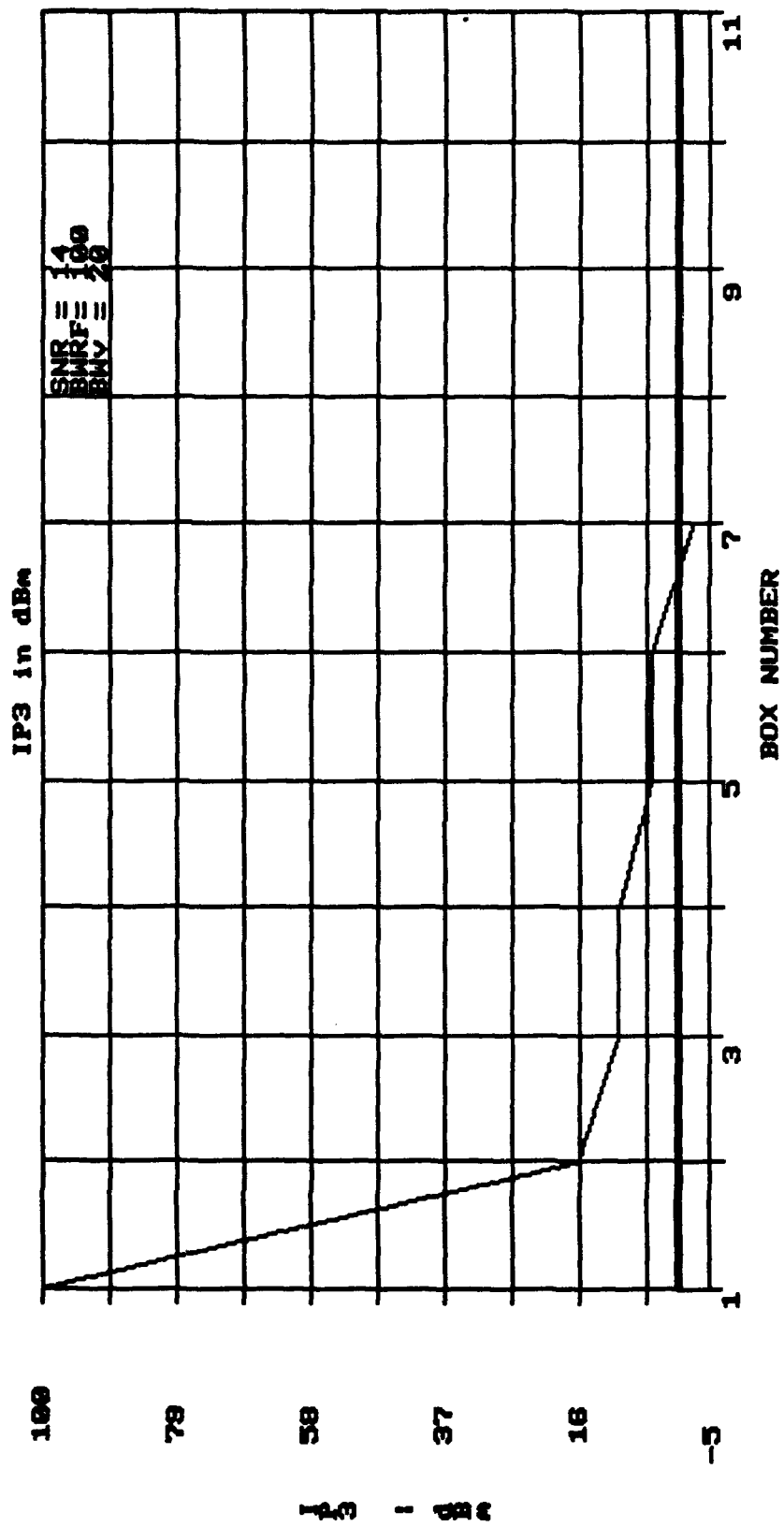
IP3 - Channelizer Thru EOD

ESM - Narrow Band Receiver Thread

The illustrated NBR thread data is the same as previously shown for the 2nd Run. The gain distribution of this thread is based on making the high NF delay add approximately 3 dB to the total noise figure.

ESM - NBR THREAD

NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
2. FRONT-END	10.0	8.0	25.0	9.0	9.0	25.0	-96.0	n/a	n/a
-BIT SWITCH	-1.5	1.5	40.0	-1.5	1.5	40.0	-114.0	n/a	n/a
-QUADPLXR	-1.0	1.0	99.0	-2.5	2.5	39.0	-114.0	n/a	n/a
-SP4T	-2.5	2.5	40.0	-5.0	5.0	34.9	-114.0	n/a	n/a
-RF AMPL	15.0	3.0	25.0	10.0	8.0	25.0	-96.0	n/a	n/a
3. FREQ CONV	7.0	11.0	26.5	16.0	9.7	25.4	-88.3	n/a	n/a
-MIXER	-7.0	7.0	15.0	-7.0	7.0	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-8.0	8.0	14.0	-114.0	n/a	n/a
-IF AMPL	15.0	3.0	30.0	7.0	11.0	26.5	-96.0	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	6.0	9.8	15.4	-98.2	n/a	n/a
5. IF AMP	18.0	3.0	30.0	24.0	9.9	28.4	-80.1	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	20.5	9.9	24.9	-83.6	n/a	n/a
7. DELAY LINE	0.0	30.5	27.0	20.5	13.0	22.8	-80.5	n/a	n/a
-100 NSEC	-25.0	25.0	99.0	-25.0	25.0	99.0	-114.0	n/a	n/a
-1ST AMP	25.0	2.5	30.0	0.0	27.5	30.0	-86.5	n/a	n/a
-100 NSEC	-25.0	25.0	99.0	-25.0	29.4	5.0	-109.6	n/a	n/a
-2ND AMP	25.0	2.5	30.0	0.0	30.5	27.0	-83.5	n/a	n/a
8. NBR	4.5	16.5	22.0	25.0	13.1	20.9	-75.9	44.2	-70.5
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF COAX	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-1ST MIXER	-7.0	7.0	15.0	-8.5	8.5	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-9.5	9.5	14.0	-114.0	n/a	n/a
-1ST IF	11.0	5.3	30.0	1.5	14.8	23.8	-97.7	n/a	n/a
-2ND MIXER	-7.0	7.0	15.0	-5.5	15.2	12.8	-104.3	n/a	n/a
-BPF	-1.0	1.0	30.0	-6.5	15.3	11.7	-105.2	n/a	n/a
-2ND IF	11.0	5.3	30.0	4.5	16.5	22.0	-93.0	n/a	n/a
-SDLVA	0.0	0.0	99.0	4.5	16.5	22.0	-93.0	53.4	-62.6

Narrow Band Receiver Thread - Gain

The gain plot shows that most of the gain build up in the NBR thread occurs toward the back-end but in front of the high noise figure delay line.

Gain(dB)

SNR = 14
SNRF = 100
BW = 20

BOX NUMBER

Gain - dB

50
39
28
17
6
-5

1 3 5 7 9 11
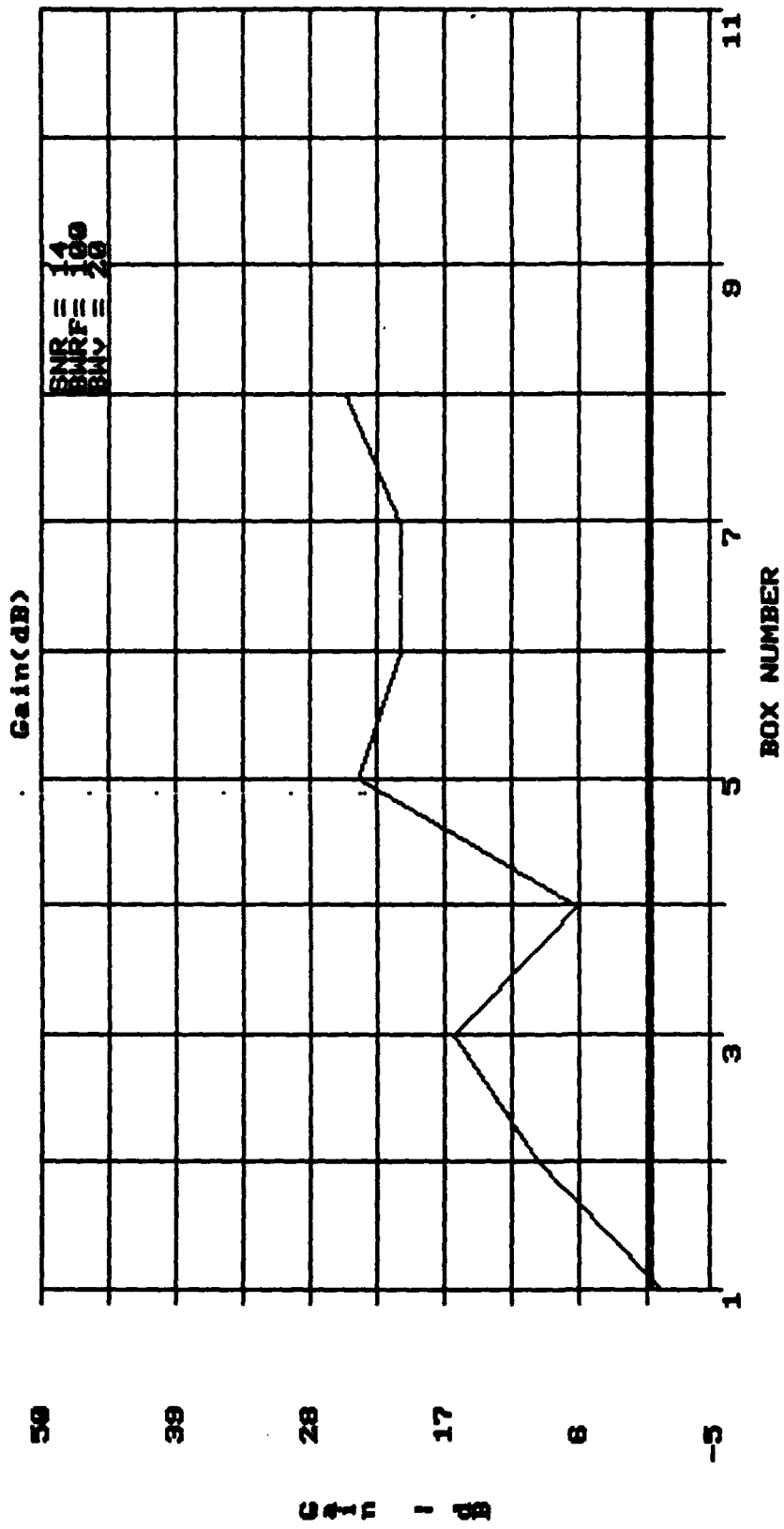
NBK THREAD - GAIN

Narrow Band Receiver Thread - Noise Figure

The impact of the large Delay Line noise figure is clearly visible by the large step of 3 dB at box 7 which is the delay line. Since sensitivity is related to noise figure, it is also apparent that the delay line is a candidate for HTS insertion.

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Noise Figure(dB)

SNR = 14
BWRF = 100
BWY = 20

NOISE FIGURE - dB

20 16 12 8 4 0

1   3   5   7   9   11

BOX NUMBER
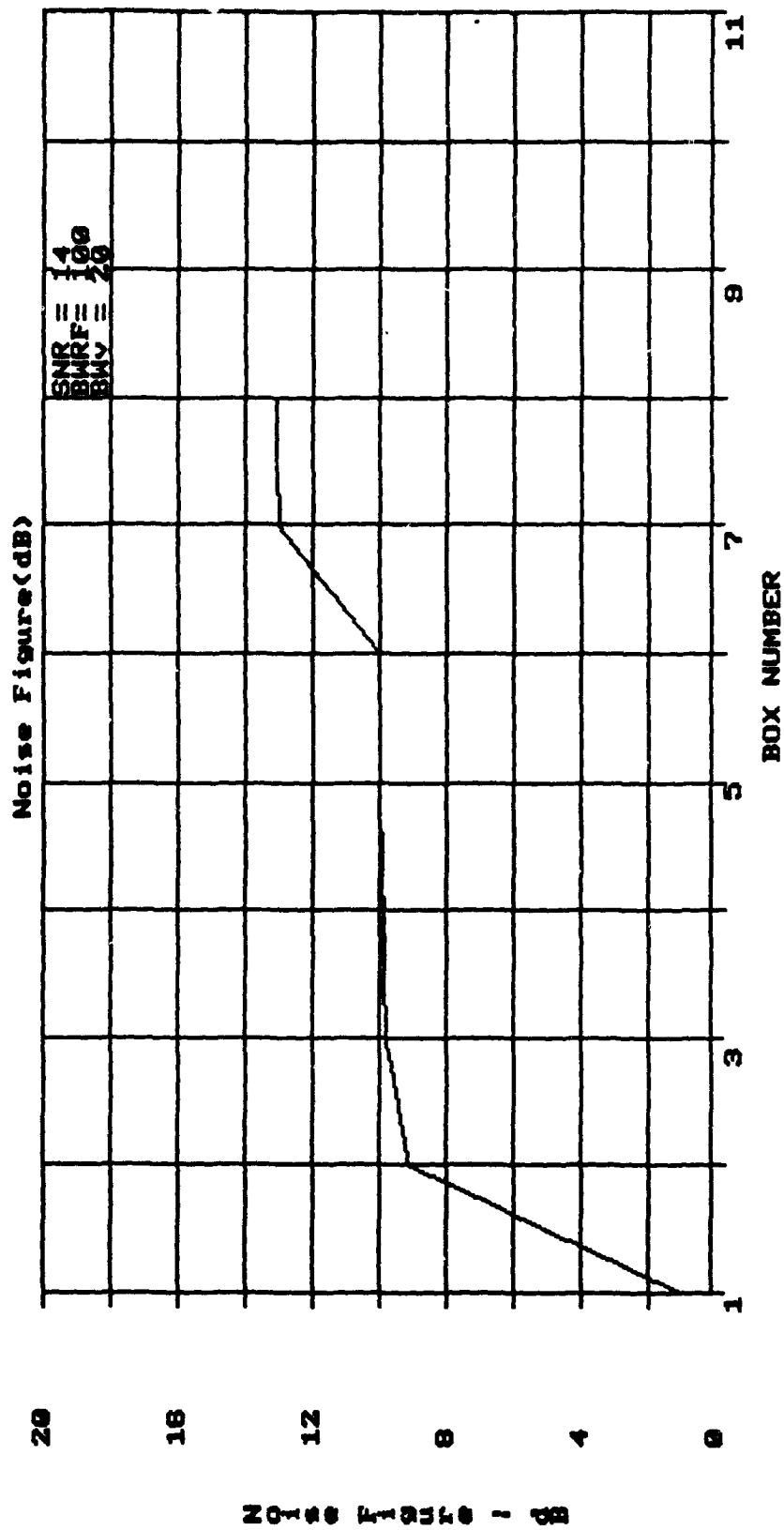
NF - NBK THREND

Narrow Band Receiver Thread - IP3

The IP3 plot shows a slight drop in IP3 reflected to the input at boxes 7 and 8 (delay line and NBR). With an ideal design the equivalent IP3 reflected to the input is expected to flatten out in a fashion similar to that seen for noise figure. The fall off in this case, while not ideal, has been kept reduced by the gain distribution approach that trades some sensitivity for improved TTDR (noise from front-end equals noise of back-end).

IP3 in dBm

SNR = 14
BWRF= 100
BWV = 20

IP3 - dBm

100

78

58

37

18

-5

1   3   5   7   9   11

BOX NUMBER
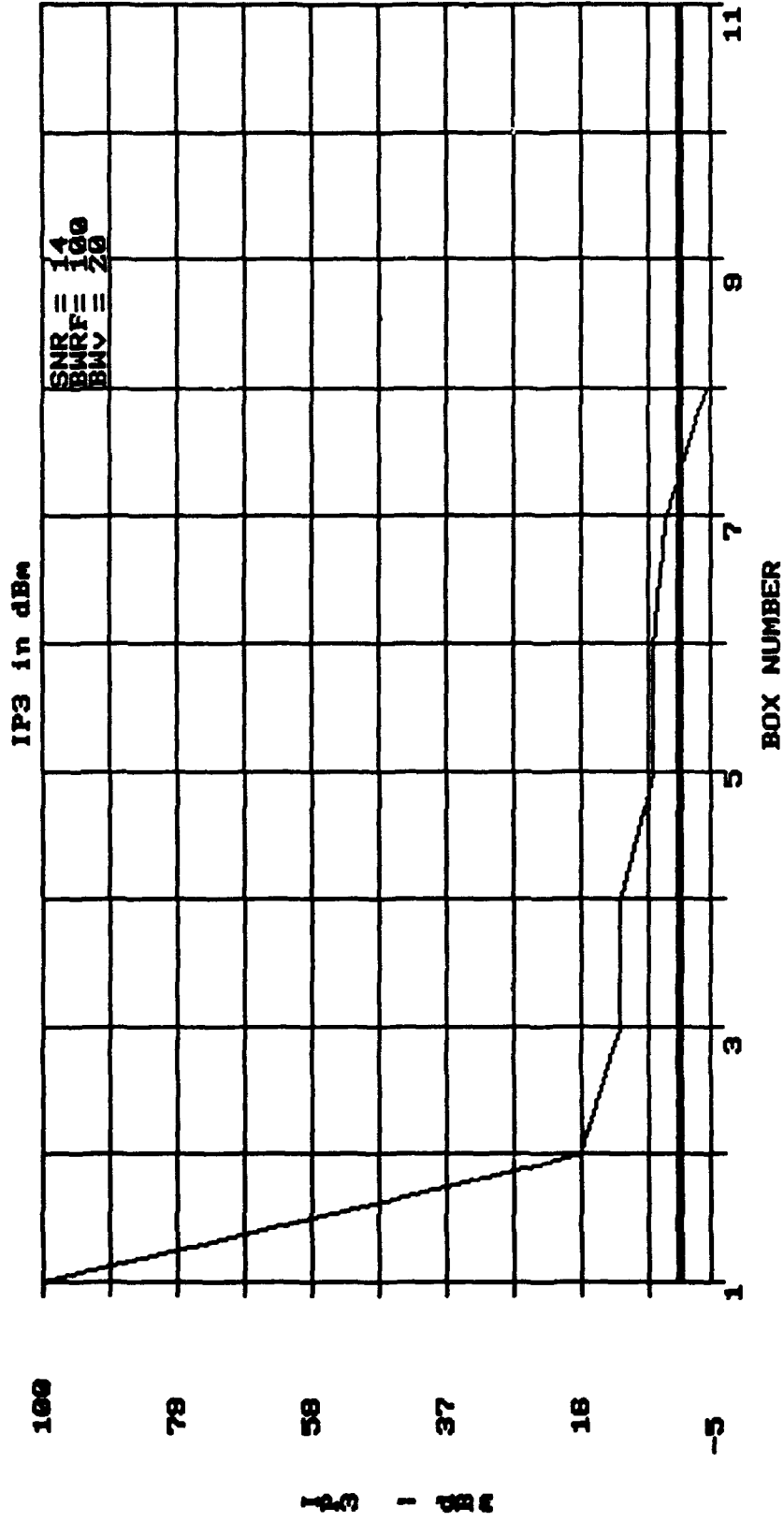
NBR THREND - LO3

Single Site IDF - HTS Insertion Candidates

The typical single site ESM system previously analyzed offers numerous possibilities for insertion. The following HTS insertion candidates will analyzed both alone and in groups using ADRATS:

- A 3 to 5 GHz 200 nsec delay line:

  3.6 dB loss (@ 5 GHz), NF=1.3 dB, IP3=40 dBm

- A 3 to 5 GHz Filter Bank comprised of 50 MHz channels:

  6 dB loss, NF=2.5 dB, IP3=40 dBm

- A 2 to 18 GHz Flow Thru Switched Filter with 2 GHz segments:

  3.2 dB loss, NF=1.1 dB, IP3=40 dBm

- A future Frequency Converter (from 2-18 GHz to 3-5 GHz)

  Mixer Estimates: Conversion Loss= 4 dB, NF=1.5 dB, IP3=30 dBm

  IF BPF Estimates: Loss=0.2 dB, NF=.05 dB, IP3=40 dBm

It should be noted that most modern ESM systems employ multiple receiver types including wide band IFM based receivers for low density portions of the spectrum, CCR's for high density areas, and tunable selectable bandwidth NBR's for when multiple or CW signals fall within the same channel.
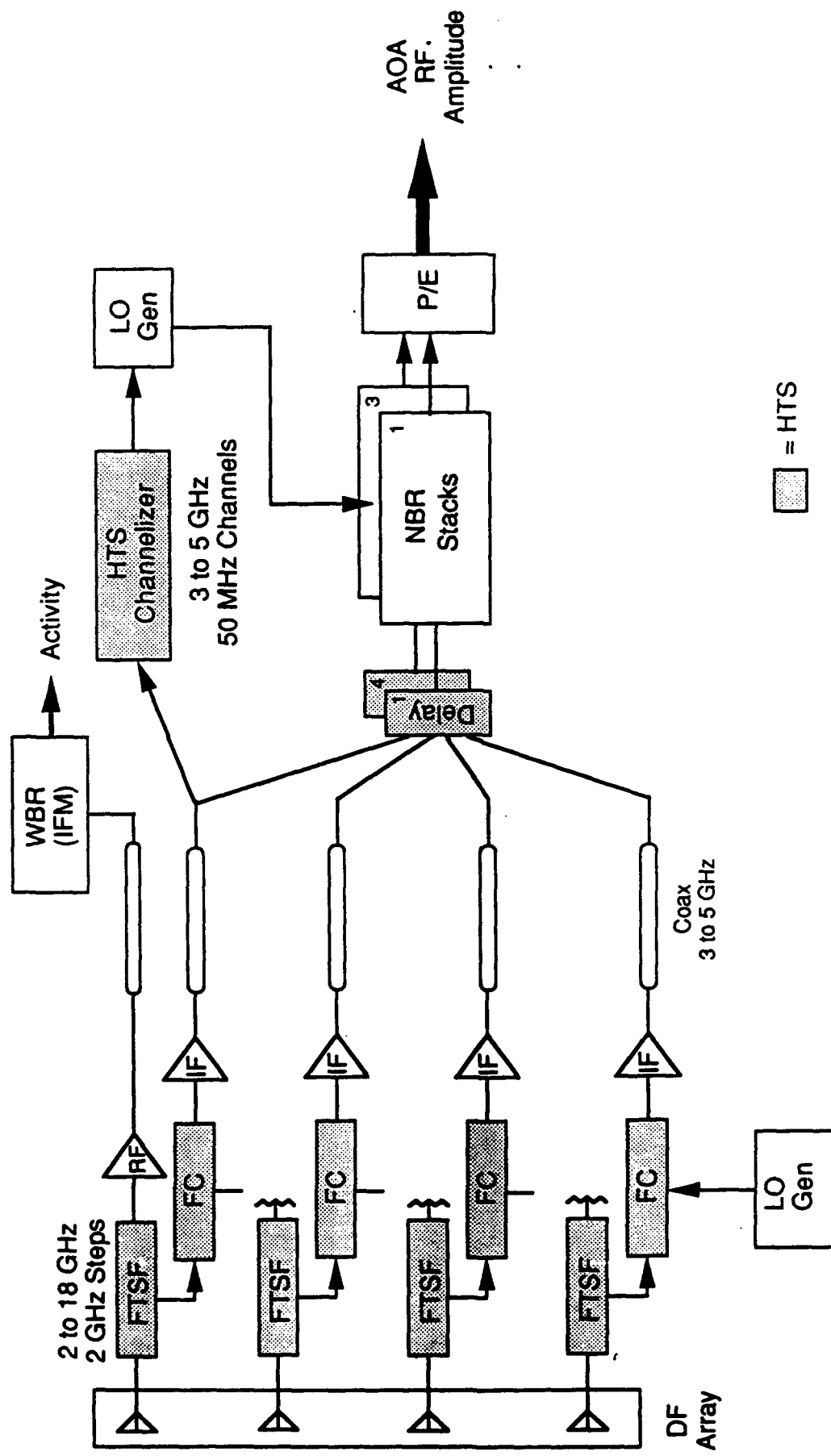
Single Site Instantaneous Direction Finding (IDF)
(4 Channel Interferometer)

NBR - HTS Delay Line 1 Insertion

The NBR thread performance of the reference runs (2nd Run and 3rd Run) were both greatly influenced by the high noise figure of a conventional wrapped coax delay line. The HTS delay line with a loss of 3.6 dB and a NF of 1.3 dB has significantly improved system performance. The delay line 1 results show that a direct replacement of the delay line (without modifying any gain distribution) produces an NBR thread sensitivity of -73.1 dBm and a TTDR of 48.1 dB. A comparison to the 2nd Run results and the 3rd Run results shows that this is an improvement of 2.6 dB and 1.0 dB in sensitivity respectively and an improvement in TTDR of 3.9 dB and 5.3 dB respectively.

2nd Run	Delta	3rd Run	Delta
-70.5	2.6	-72.1	1.0
44.2	3.9	42.8	5.3

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NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
2. FRONT-END	10.0	8.0	25.0	9.0	9.0	25.0	-96.0	n/a	n/a
-BIT SWITCH	-1.5	1.5	40.0	-1.5	1.5	40.0	-114.0	n/a	n/a
-QUADPLXR	-1.0	1.0	99.0	-2.5	2.5	39.0	-114.0	n/a	n/a
-SP4T	-2.5	2.5	40.0	-5.0	5.0	34.9	-114.0	n/a	n/a
-RF AMPL	15.0	3.0	25.0	10.0	8.0	25.0	-96.0	n/a	n/a
3. FREQ CONV	7.0	11.0	26.5	16.0	9.7	25.4	-88.3	n/a	n/a
-MIXER	-7.0	7.0	15.0	-7.0	7.0	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-8.0	8.0	14.0	-114.0	n/a	n/a
-IF AMPL	15.0	3.0	30.0	7.0	11.0	26.5	-96.0	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	6.0	9.8	15.4	-98.2	n/a	n/a
5. IF AMP	18.0	3.0	30.0	24.0	9.9	28.4	-80.1	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	20.5	9.9	24.9	-83.6	n/a	n/a
7. HTS DELAY	-3.6	1.3	40.0	16.9	10.0	21.2	-87.1	n/a	n/a
-HTS 200NS	-3.6	1.3	40.0	-3.6	1.3	40.0	-116.3	n/a	n/a
8. NBR	4.5	16.5	22.0	21.4	10.3	20.4	-82.3	48.1	-73.1
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF COAX	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-1ST MIXER	-7.0	7.0	15.0	-8.5	8.5	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-9.5	9.5	14.0	-114.0	n/a	n/a
-1ST IF	11.0	5.3	30.0	1.5	14.8	23.8	-97.7	n/a	n/a
-2ND MIXER	-7.0	7.0	15.0	-5.5	15.2	12.8	-104.3	n/a	n/a
-BPF	-1.0	1.0	30.0	-6.5	15.3	11.7	-105.2	n/a	n/a
-2ND IF	11.0	5.3	30.0	4.5	16.5	22.0	-93.0	n/a	n/a
-SDLVA	0.0	0.0	99.0	4.5	16.5	22.0	-93.0	53.4	-62.6

ESMNBRd1.RFH

NBR - HTS Delay Line 2 Insertion

The Delay Line 2 results are for the reference system (2nd Run or 3rd Run) with the gain distribution made to account for the lower loss of the delay line. The result is about 1 dB less sensitivity than the delay line 1 data but over 2 dB increase in dynamic range (sensitivity now equals -72.1 dBm and TTDR is 50.3 dB). A comparison to the prior reference run is as follows:

2nd Run	Delta	3rd Run	Delta
-70.5	1.6	-72.1	0.0
44.2	6.1	42.8	7.5

A 7.5 dB improvement in spur free TTDR is certainly impressive. It should be noted that the CCR relies on spur free detection at maximum sensitivity from both the Channelizer and NBR. Hence, the CCR sensitivity is approximately the lowest sensitivity of the two and the TTDR is approximately the worse case TTDR of the two. Approximately is used since the channelizer has many channels while the NBR has only one.

NBR - HTS DELAY LINE 2

NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
2. FRONT-END	10.0	8.0	25.0	9.0	9.0	25.0	-96.0	n/a	n/a
-BIT SWITCH	-1.5	1.5	40.0	-1.5	1.5	40.0	-114.0	n/a	n/a
-QUADPLXR	-1.0	1.0	99.0	-2.5	2.5	39.0	-114.0	n/a	n/a
-SP4T	-2.5	2.5	40.0	-5.0	5.0	34.9	-114.0	n/a	n/a
-RF AMPL	15.0	3.0	25.0	10.0	8.0	25.0	-96.0	n/a	n/a
3. FREQ CONV	7.0	11.0	26.5	16.0	9.7	25.4	-88.3	n/a	n/a
-MIXER	-7.0	7.0	15.0	-7.0	7.0	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-8.0	8.0	14.0	-114.0	n/a	n/a
-IF AMPL	15.0	3.0	30.0	7.0	11.0	26.5	-96.0	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	6.0	9.8	15.4	-98.2	n/a	n/a
5. IF AMP	12.0	3.0	30.0	18.0	9.9	25.5	-86.1	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	14.5	10.0	22.0	-89.5	n/a	n/a
7. HTS DELAY	-3.6	1.3	40.0	10.9	10.0	18.4	-93.1	n/a	n/a
-HTS 200NS	-3.6	1.3	40.0	-3.6	1.3	40.0	-116.3	n/a	n/a
8. NBR	6.5	14.9	23.0	17.4	10.9	20.8	-85.7	50.3	-72.1
-IF COAX	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-1ST MIXER	-7.0	7.0	15.0	-8.5	8.5	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-9.5	9.5	14.0	-114.0	n/a	n/a
-1ST IF	12.0	4.0	30.0	2.5	13.5	24.5	-98.0	n/a	n/a
-2ND MIXER	-7.0	7.0	15.0	-4.5	13.9	13.1	-104.6	n/a	n/a
-BPF	-1.0	1.0	30.0	-5.5	14.0	12.0	-105.5	n/a	n/a
-2ND IF	12.0	4.0	30.0	6.5	14.9	23.0	-92.6	n/a	n/a
-SDLVA	0.0	0.0	99.0	6.5	14.9	23.0	-92.6	54.0	-64.5

(BWrf=   100.0 ,BWv=   20.0 ,TSSd=-65.0 ,BWdet=   20.0 ,Eq=Linear ,SNR= 14)

ESMNBRd1.RFH

NBR - HTS Delay line 3(Present Design)

The latest HTS 22 nanosecond delay line (4/25/94) has been found to have a a loss of about 0.04 dB/nsec or 9 dB for 200 nsec's as compared to the ultimate goal of 0.015 dB/nsec or about 3.5 dB per 200 nsec's. The wrapped coax cable presently in use has about 25 dB per 100 nsec which is many times that of even the current HTS product. The results using the current 9 dB loss along with a low gain amplifier to make up this loss achieves almost the same performance as the delay line 1 results. The sensitivity of both is -73.1 dBm with the HTS delay line 3 having a TTDR of 47.9 dB as compared to the 48.1 dB of the delay 1. It is evident that the lower the delay line losses the better but that most of the improvement is realized with the current design.

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NBR - HTS DELAY LINE 3

NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
2. FRONT-END	10.0	8.0	25.0	9.0	9.0	25.0	-96.0	n/a	n/a
-BIT SWITCH	-1.5	1.5	40.0	-1.5	1.5	40.0	-114.0	n/a	n/a
-QUADPLXR	-1.0	1.0	99.0	-2.5	2.5	39.0	-114.0	n/a	n/a
-SP4T	-2.5	2.5	40.0	-5.0	5.0	34.9	-114.0	n/a	n/a
-RF AMPL	15.0	3.0	25.0	10.0	8.0	25.0	-96.0	n/a	n/a
3. FREQ CONV	7.0	11.0	26.5	16.0	9.7	25.4	-88.3	n/a	n/a
-MIXER	-7.0	7.0	15.0	-7.0	7.0	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-8.0	8.0	14.0	-114.0	n/a	n/a
-IF AMPL	15.0	3.0	30.0	7.0	11.0	26.5	-96.0	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	6.0	9.8	15.4	-98.2	n/a	n/a
5. IF AMP	16.0	3.0	30.0	22.0	9.9	27.6	-82.1	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	18.5	10.0	24.1	-85.5	n/a	n/a
7. HTS DELAY	-1.0	11.7	29.9	17.5	10.0	22.3	-86.5	n/a	n/a
-HTS 200NS	-9.0	4.5	40.0	-9.0	4.5	40.0	-118.5	n/a	n/a
-Gain	8.0	4.0	30.0	-1.0	11.7	29.9	-103.3	n/a	n/a
8. NBR	4.5	16.5	22.0	22.0	10.4	20.7	-81.6	47.9	-73.1
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF COAX	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-1ST MIXER	-7.0	7.0	15.0	-8.5	8.5	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-9.5	9.5	14.0	-114.0	n/a	n/a
-1ST IF	11.0	5.3	30.0	1.5	14.8	23.8	-97.7	n/a	n/a
-2ND MIXER	-7.0	7.0	15.0	-5.5	15.2	12.8	-104.3	n/a	n/a
-BPF	-1.0	1.0	30.0	-6.5	15.3	11.7	-105.2	n/a	n/a
-2ND IF	11.0	5.3	30.0	4.5	16.5	22.0	-93.0	n/a	n/a
-SDLVA	0.0	0.0	99.0	4.5	16.5	22.0	-93.0	53.4	-62.6

ESMNBRD3.RFH

Channelizer - HTS Filter Bank

A conventional channelizer filter bank may have an insertion loss that varies from about 12 dB up to 35 dB. A typical value of 15 dB loss is used in the 2nd Run as compared to the HTS loss estimate of 6 dB with a noise figure of only 2.8 dB. Inclusion of the HTS filter bank into the 2nd Run architecture is seen to produce the same sensitivity but an improvement in TTDR of 4.5 dB (from 46.8 dB to 51.3 dB). A less apparent advantage of HTS is it's higher Q that makes direct the desired 50 MHz channelization possible (without further mixing) while conventional lumped element filter banks are generally restricted to 100 MHz channelization in this band.

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CCR-HTS FILTER BANK

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| NAME | COMPONENTS | | | TOTALS | | | | RECEIVERS | |
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
2. FRONT-END	10.0	8.0	25.0	9.0	9.0	25.0	-96.0	n/a	n/a
-BIT SWITCH	-1.5	1.5	40.0	-1.5	1.5	40.0	-114.0	n/a	n/a
-QUADPLXR	-1.0	1.0	99.0	-2.5	2.5	39.0	-114.0	n/a	n/a
-SP4T	-2.5	2.5	40.0	-5.0	5.0	34.9	-114.0	n/a	n/a
-RF AMPL	15.0	3.0	25.0	10.0	8.0	25.0	-96.0	n/a	n/a
3. FREQ CONV	7.0	11.0	26.5	16.0	9.7	25.4	-88.3	n/a	n/a
-MIXER	-7.0	7.0	15.0	-7.0	7.0	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-8.0	8.0	14.0	-114.0	n/a	n/a
-IF AMPL	15.0	3.0	30.0	7.0	11.0	26.5	-96.0	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	6.0	9.8	15.4	-98.2	n/a	n/a
5. IF AMP	12.0	3.0	30.0	18.0	9.9	25.5	-86.1	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	14.5	10.0	22.0	-89.5	n/a	n/a
7. CHANNELZR	1.5	5.7	23.9	16.0	10.0	20.7	-88.0	51.3	-72.2
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-Coax	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-AMPLIFIER	9.0	4.0	30.0	7.5	5.5	30.0	-101.0	n/a	n/a
-FILTERBNK	-6.0	2.5	40.0	1.5	5.7	23.9	-106.8	n/a	n/a
-SDLVA	0.0	0.0	99.0	1.5	5.7	23.9	-106.8	55.2	-60.5

ESMCH.RFH

ESM - 5th Run (FTSF Insertion vs. Quadruplexer)

The HTS Flowthrough Switched Preselector (FTSW) is an unusual device that can be applied to ESM, shared aperture and other applications. The FTSF is a switched filter bank of eight 2 GHz frequency segments or filters that in total cover 2 to 18 GHz. It has two outputs. In this ESM application one of the outputs is a selected 2 GHz segment being sent to the CCR while the other is sent to a wide band IFM based receiver. The FTSF has an insertion loss of 3.2 dB maximum while the 2nd Run Quadruplexer and SP4T switch combination had a combined loss of 3.5 dB. Therefore, it is not too surprising that the FTSF insertion into the 2nd Run architecture only increased sensitivity and TTDR by about .3 dB. However, the FTSW has another advantage for which there is no known figure of merit that is due to reduced out-of-band spur generation. The 2nd Run Quadruplexer can have filters at RF that are many time the bandwidth at IF (i.e., 10 to 18 GHz vs. 3 to 5 GHz). Strong signals that fall outside of the 2 GHz segment of interest will reach the first amplifier or other non-linear devices and create spurious signals that will fall within the 2 GHz segment of interest. In dense environments such as within a naval fleet this can be a serious problem that is conventionally analyzed using computer simulations. Again, the FTSF eliminates this excessive RF bandwidth and associated source of spurs.

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NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
2. FRONT-END	10.0	6.8	25.0	9.0	7.8	25.0	-97.2	n/a	n/a
-BIT SWITCH	-1.5	1.5	40.0	-1.5	1.5	40.0	-114.0	n/a	n/a
-HTS FTSW	-3.2	1.1	40.0	-4.7	2.6	35.1	-116.1	n/a	n/a
-RF AMPL	14.7	3.0	25.0	10.0	6.8	25.0	-97.2	n/a	n/a
3. FREQ CONV	7.0	11.0	26.5	16.0	8.7	25.4	-89.3	n/a	n/a
-MIXER	-7.0	7.0	15.0	-7.0	7.0	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-8.0	8.0	14.0	-114.0	n/a	n/a
-IF AMPL	15.0	3.0	30.0	7.0	11.0	26.5	-96.0	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	6.0	8.9	15.4	-99.1	n/a	n/a
5. IF AMP	18.0	3.0	30.0	24.0	9.0	28.4	-81.0	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	20.5	9.0	24.9	-84.5	n/a	n/a
7. Divider	n/a	n/a	n/a	20.5	9.0	24.9	n/a	n/a	n/a
8. CHANNELZR	-4.5	7.4	15.0	16.0	9.0	13.9	-89.0	47.1	-72.8
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF CABLE	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-AMPLIFIER	12.0	3.0	30.0	10.5	4.5	30.0	-99.0	n/a	n/a
-FILTERBNK	-15.0	15.0	99.0	-4.5	7.4	15.0	-111.1	n/a	n/a
-SDLVA	0.0	0.0	99.0	-4.5	7.4	15.0	-111.1	49.3	-54.5
9. DELAY LINE	0.0	30.5	27.0	20.5	12.5	22.8	-81.0	n/a	n/a
-100 NSEC	-25.0	25.0	99.0	-25.0	25.0	99.0	-114.0	n/a	n/a
-1ST AMP	25.0	2.5	30.0	0.0	27.5	30.0	-86.5	n/a	n/a
-100 NSEC	-25.0	25.0	99.0	-25.0	29.4	5.0	-109.6	n/a	n/a
-2ND AMP	25.0	2.5	30.0	0.0	30.5	27.0	-83.5	n/a	n/a
10. NB RCVR	4.5	16.5	22.0	25.0	12.6	20.9	-76.4	44.6	-70.9
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF COAX	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-1ST MIXER	-7.0	7.0	15.0	-8.5	8.5	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-9.5	9.5	14.0	-114.0	n/a	n/a
-1ST IF	11.0	5.3	30.0	1.5	14.8	23.8	-97.7	n/a	n/a
-2ND MIXER	-7.0	7.0	15.0	-5.5	15.2	12.8	-104.3	n/a	n/a
-BPF	-1.0	1.0	99.0	-6.5	15.3	11.8	-105.2	n/a	n/a
-2ND IF	11.0	5.3	30.0	4.5	16.5	22.0	-93.0	n/a	n/a
-DLVA	0.0	0.0	99.0	4.5	16.5	22.0	-93.0	53.4	-62.6

ESM2ND.RFH

Centimeter

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 mm

1 2 3 4 5

Inches

1.0

1.1

1.25   1.4   1.6

2.8   2.5
3.2   2.2
3.6
   2.0
   1.8

MANUFACTURED TO AIIM STANDARDS

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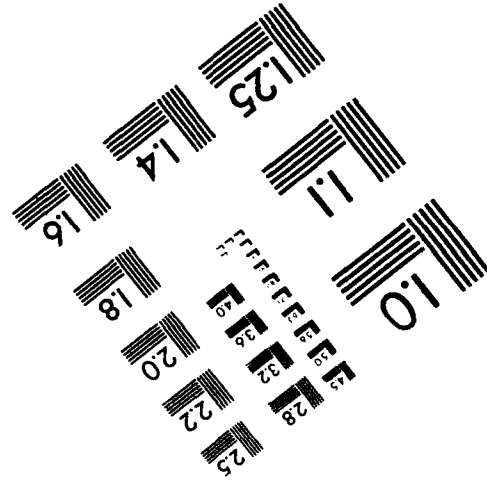
ESM-4th Run (Switched Filter Bank vs HTS FTSF)

Conventional switched RF filter banks are available that can provide the 2 GHz bandwidths of the FTSF but at slight higher loss (6 dB loss and 6 dB NF). The 4th Run data is for the 2nd Run architecture but with a switched RF filter bank that replaces the Quadruplexer and associated SP4T switch. The result is a 1 to 2 dB lower sensitivity and lower TTDR for both the channelizer and NBR threads. What is gained is improved performance in dense environments due to elimination of out-of-band spur generation. This is a very difficult capability to quantify with the current method of dense emitter simulations being costly and the results uncertain (an attempt will be made in the Dynamic Range Considerations Section to generate a figure-of-merit that reflects the advantages of matched RF filtering). A comparison of these results to those for the 5th Run (FTSF insertion) with similar capabilities is as follows:

	Sensitivity	TTDR
Channelizer Path		
5th Run	-72.8	47.1
4th Run	-70.9	45.8
Delta	1.9 dB	1.3 dB
NBR Path		
5th Run	-70.9	44.6
4th Run	-69.3	43.5
Delta	1.6 dB	1.1 dB

The relatively small improvements associated with FTSF insertion can be traced to the relative large loss of the FTSF. However, this can be improved.

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NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
2. FRONT-END	10.0	10.5	25.0	9.0	11.5	25.0	-93.5	n/a	n/a
-BIT SWITCH	-1.5	1.5	40.0	-1.5	1.5	40.0	-114.0	n/a	n/a
-SWFILTERS	-6.0	6.0	40.0	-7.5	7.5	33.0	-114.0	n/a	n/a
-RF AMPL	17.5	3.0	25.0	10.0	10.5	25.0	-93.5	n/a	n/a
3. FREQ CONV	7.0	11.0	26.5	16.0	11.9	25.4	-86.1	n/a	n/a
-MIXER	-7.0	7.0	15.0	-7.0	7.0	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-8.0	8.0	14.0	-114.0	n/a	n/a
-IF AMPL	15.0	3.0	30.0	7.0	11.0	26.5	-96.0	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	6.0	12.0	15.4	-96.0	n/a	n/a
5. IF AMP	18.0	3.0	30.0	24.0	12.1	28.4	-77.9	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	20.5	12.1	24.9	-81.4	n/a	n/a
7. Divider	n/a	n/a	n/a	20.5	12.1	24.9	n/a	n/a	n/a
8. CHANNELZR	-4.5	7.4	15.0	16.0	12.1	13.9	-85.9	45.8	-70.9
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF CABLE	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-AMPLIFIER	12.0	3.0	30.0	10.5	4.5	30.0	-99.0	n/a	n/a
-FILTERBNK	-15.0	15.0	99.0	-4.5	7.4	15.0	-111.1	n/a	n/a
-SDLVA	0.0	0.0	99.0	-4.5	7.4	15.0	-111.1	49.3	-54.5
9. DELAY LINE	0.0	30.5	27.0	20.5	14.2	22.8	-79.3	n/a	n/a
-100 NSEC	-25.0	25.0	99.0	-25.0	25.0	99.0	-114.0	n/a	n/a
-1ST AMP	25.0	2.5	30.0	0.0	27.5	30.0	-86.5	n/a	n/a
-100 NSEC	-25.0	25.0	99.0	-25.0	29.4	5.0	-109.6	n/a	n/a
-2ND AMP	25.0	2.5	30.0	0.0	30.5	27.0	-83.5	n/a	n/a
10. NB RCVR	4.5	16.5	22.0	25.0	14.2	20.9	-74.8	43.5	-69.3
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF COAX	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-1ST MIXER	-7.0	7.0	15.0	-8.5	8.5	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-9.5	9.5	14.0	-114.0	n/a	n/a
-1ST IF	11.0	5.3	30.0	1.5	14.8	23.8	-97.7	n/a	n/a
-2ND MIXER	-7.0	7.0	15.0	-5.5	15.2	12.8	-104.3	n/a	n/a
-BPF	-1.0	1.0	99.0	-6.5	15.3	11.8	-105.2	n/a	n/a
-2ND IF	11.0	5.3	30.0	4.5	16.5	22.0	-93.0	n/a	n/a
-DLVA	0.0	0.0	99.0	4.5	16.5	22.0	-93.0	53.4	-62.6

ESM - Combined HTS BIT Switch & Filterbank

The FTSF device has too much loss (3.2 dB) to be an effective replacement for available switched multiplexed filter banks (6 dB) that can also provide the 2 GHz segmentation from 2 to 18 GHz. There are a number of approaches that can be used to improve FTSF performance.

1. The 16 to 18 GHz is presently the last FTSF section producing the highest loss of 3.2 dB. This is the high loss point of all conventional components in the string. Reversing the order of filter section would tend to equalize the remaining system losses.

2. The present serial switched filters and hybrids used in the FTSF leads to the high loss. A parallel approach or binary division approach might yield a much lower loss. For example a section splits the band in two (2 to 6 and 6 to 18 GHz). The following sections split the ranges further and etc.. The goal remains the ability to select one of eight segments of 2 GHz. Another approach that might be considered is to combined hybrids and quadruplexers.

3. The 2 to 18 GHz BIT switch found in most front-ends has about 1.5 dB loss that adds directly to the noise figure. An HTS device that combines a BIT switch with 0.2 dB loss and a filter bank with 1 dB loss would produce a channelizer thread sensitivity of -77.4 dBm as compared to the -70.9 dBm on the 4th Run with a conventional switched filter bank (a gain of 6.5 dB). Similar improvements are also seen in the NBR thread sensitivities.

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NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
2. FRONT-END	16.3	3.8	25.0	15.3	4.8	25.0	-93.9	n/a	n/a
-HTS BIT	-0.2	0.1	40.0	-0.2	0.1	40.0	-114.2	n/a	n/a
-HTS FBANK	-1.0	0.3	40.0	-1.2	0.4	36.5	-114.8	n/a	n/a
-RF AMPL	17.5	3.0	25.0	16.3	3.8	25.0	-93.9	n/a	n/a
3. FREQ CONV	7.0	11.0	26.5	22.3	5.3	25.4	-86.4	n/a	n/a
-MIXER	-7.0	7.0	15.0	-7.0	7.0	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-8.0	8.0	14.0	-114.0	n/a	n/a
-IF AMPL	15.0	3.0	30.0	7.0	11.0	26.5	-96.0	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	12.3	5.4	15.4	-96.3	n/a	n/a
5. IF AMP	18.0	3.0	30.0	30.3	5.4	28.4	-78.3	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	26.8	5.4	24.9	-81.8	n/a	n/a
7. Divider	n/a	n/a	n/a	26.8	5.4	24.9	n/a	n/a	n/a
8. CHANNELZR	-4.5	7.4	15.0	22.3	5.4	13.9	-86.3	46.0	-77.4
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF CABLE	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-AMPLIFIER	12.0	3.0	30.0	10.5	4.5	30.0	-99.0	n/a	n/a
-FILTERBNK	-15.0	15.0	99.0	-4.5	7.4	15.0	-11? ?	n/a	n/a
-SDLVA	0.0	0.0	99.0	-4.5	7.4	15.0	-1.	49.3	-54.5
9. DELAY LINE	0.0	30.5	27.0	26.8	7.7	22.8	-79.5	n/a	n/a
-100 NSEC	-25.0	25.0	99.0	-25.0	25.0	99.0	-114.0	n/a	n/a
-1ST AMP	25.0	2.5	30.0	0.0	27.5	30.0	-86.5	n/a	n/a
-100 NSEC	-25.0	25.0	99.0	-25.0	29.4	5.0	-109.6	n/a	n/a
-2ND AMP	25.0	2.5	30.0	0.0	30.5	27.0	-83.5	n/a	n/a
10. NB RCVR	4.5	16.5	22.0	31.3	7.7	20.9	-75.0	43.6	-75.8
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF COAX	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-1ST MIXER	-7.0	7.0	15.0	-8.5	8.5	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-9.5	9.5	14.0	-114.0	n/a	n/a
-1ST IF	11.0	5.3	30.0	1.5	14.8	23.8	-97.7	n/a	n/a
-2ND MIXER	-7.0	7.0	15.0	-5.5	15.2	12.8	-104.3	n/a	n/a
-BPF	-1.0	1.0	99.0	-6.5	15.3	11.8	-105.2	n/a	n/a
-2ND IF	11.0	5.3	30.0	4.5	16.5	22.0	-93.0	n/a	n/a
-DLVA	0.0	0.0	99.0	4.5	16.5	22.0	-93.0	53.4	-62.6

ESM4TH.RFH

HTS: RF FTSF, IF Delay Lines, and IF Filter Banks

The three currently planned devices include the RF Flow Thru Filter Bank, Delay lines, and IF Filter Bank. Each of these have been separately addressed relative to the ESM system (2nd Run). It should be noted that the CCR performance is the worse case performance of either the channelizer or NBR. In the 2nd Run the worse case was the NBR thread with a sensitivity of -70.5 dBm and a TTDR of 44.3 dB. In the composite HTS run the worse case remains the NBR thread (now much closer to the channelizer thread) with a sensitivity of -71.6 dBm (or 1.1 dB improvement) and a TTDR of 50.4 dB (or a 6.1 dB increase). The channelizer thread has improved 0.5 dB in sensitivity and 4.8 dB in TTDR. If this were not the case the channelizer would be the controlling worse case thread.

ESM:HTS-FTSF,DELAY&FBANK

DATE:04-15-1994   TIME=09:49:50

NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
2. FE-FTSF	10.0	6.8	25.0	9.0	7.8	25.0	-97.2	n/a	n/a
-BIT SWITCH	-1.5	1.5	40.0	-1.5	1.5	40.0	-114.0	n/a	n/a
-HTS FTSW	-3.2	1.1	40.0	-4.7	2.6	35.1	-116.1	n/a	n/a
-RF AMPL	14.7	3.0	25.0	10.0	6.8	25.0	-97.2	n/a	n/a
3. FREQ CONV	7.0	11.0	26.5	16.0	8.7	25.4	-89.3	n/a	n/a
-MIXER	-7.0	7.0	15.0	-7.0	7.0	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-8.0	8.0	14.0	-114.0	n/a	n/a
-IF AMPL	15.0	3.0	30.0	7.0	11.0	26.5	-96.0	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	6.0	8.9	15.4	-99.1	n/a	n/a
5. IF AMP	12.0	3.0	30.0	18.0	9.0	25.5	-87.0	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	14.5	9.0	22.0	-90.5	n/a	n/a
7. Divider	n/a	n/a	n/a	14.5	9.0	22.0	n/a	n/a	n/a
8. HTS CHANZR	1.5	5.7	23.9	16.0	9.1	20.7	-88.9	51.6	-72.8
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF CABLE	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-AMPLIFIER	9.0	4.0	30.0	7.5	5.5	30.0	-101.0	n/a	n/a
-HTS FILTER	-6.0	2.5	40.0	1.5	5.7	23.9	-106.8	n/a	n/a
-SDLVA	0.0	0.0	99.0	1.5	5.7	23.9	-106.8	55.2	-60.5
9. HTS DELAY	-3.6	1.3	40.0	10.9	9.0	18.4	-94.1	n/a	n/a
-200NSEC	-3.6	1.3	40.0	-3.6	1.3	40.0	-116.3	n/a	n/a
10. NB RCVR	4.5	16.5	22.0	15.4	10.6	19.4	-88.0	50.4	-71.6
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF COAX	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-1ST MIXER	-7.0	7.0	15.0	-8.5	8.5	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-9.5	9.5	14.0	-114.0	n/a	n/a
-1ST IF	11.0	5.3	30.0	1.5	14.8	23.8	-97.7	n/a	n/a
-2ND MIXER	-7.0	7.0	15.0	-5.5	15.2	12.8	-104.3	n/a	n/a
-BPF	-1.0	1.0	99.0	-6.5	15.3	11.8	-105.2	n/a	n/a
-2ND IF	11.0	5.3	30.0	4.5	16.5	22.0	-93.0	n/a	n/a
-DLVA	0.0	0.0	99.0	4.5	16.5	22.0	-93.0	53.4	-62.6

ESM5th.RFH

HTS Mixer and Bandpass Filter

The conversion loss of a conventional double sideband mixer is on the order of 7 dB. It is presently uncertain as to how much this can be lowered in a future HTS implementation (note: this is the only future device being consider during this the 'planned devices' portion of the study). This could be important in that if loss is sufficiently low it may be possible to combine the FTSF with an HTS frequency converter consisting of an HTS mixer and BPF and completely eliminate expensive RF amplification. The data for the HTS mixer and BPF shows that without RF amplification the sensitivity and TTDR (-71.3 dBm and 46.2 dB respectively) are less than that of the 2nd Run with RF amplification (-72.3 dBm and 46.8 dB respectively). One reason for this poor performance is that the mixer loss is estimated at 4 dB of which 3 dB is attributed to observing only one of the two sidebands. A more complex single sideband could reduce this loss.

HTS MIXER & BPF

NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
2. FRONT-END	-4.7	2.6	35.1	-5.7	3.6	35.1	-116.1	n/a	n/a
⎮-BIT SWITCH	-1.5	1.5	40.0	-1.5	1.5	40.0	-114.0	n/a	n/a
⎮-HTS FTSF	-3.2	1.1	40.0	-4.7	2.6	35.1	-116.1	n/a	n/a
3. FREQ CONV	21.7	6.1	30.0	16.0	11.4	30.0	-86.6	n/a	n/a
⎮-HTS MIXER	-4.0	1.5	30.0	-4.0	1.5	30.0	-116.5	n/a	n/a
⎮-HTS BPF	-0.2	0.1	40.0	-4.2	1.6	29.4	-116.6	n/a	n/a
⎮-IF AMPL	25.9	3.0	30.0	21.7	6.1	30.0	-86.2	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	6.0	11.4	20.0	-96.6	n/a	n/a
5. IF AMP	18.0	3.0	30.0	24.0	11.5	29.4	-78.5	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	20.5	11.5	25.9	-82.0	n/a	n/a
7. CHANNELZR	-4.5	7.4	15.0	16.0	11.5	14.1	-86.5	46.2	-71.3
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
⎮-Coax	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
⎮-AMPLIFIER	12.0	3.0	30.0	10.5	4.5	30.0	-99.0	n/a	n/a
⎮-FILTERBNK	-15.0	15.0	99.0	-4.5	7.4	15.0	-111.1	n/a	n/a
⎮-SDLVA	0.0	0.0	99.0	-4.5	7.4	15.0	-111.1	49.3	-54.5

CHTHMIX.RFH

HTS SSB Mixer, BPF and BIT SW

It is apparent that an HTS version of a convention double sideband mixer frequency converter alone is still too lossy to allow elimination of RF amplification. A more ambitious plan is to use single side-band mixing in the frequency converter along with an HTS Bit switch to further reduce loss. The resulting data for such an expansive approach still only affords about a 1 dB increase in sensitivity and 0.7 dB improvement in TTDR relative to the 2nd Run data. It would appear that HTS mixer insertion into a conventional ESM architecture does not afford sufficient performance improvement to warrant it's incorporation.

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HTS SSBMIXER,BPF,BIT SW

NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
2. FRONT-END	-3.4	1.2	35.1	-4.4	2.2	35.1	-116.2	n/a	n/a
-HTS SWITCH	-0.2	0.1	40.0	-0.2	0.1	40.0	-114.2	n/a	n/a
-HTS FTSF	-3.2	1.1	40.0	-3.4	1.2	35.1	-116.2	n/a	n/a
3. FREQ CONV	24.3	4.2	30.0	19.9	7.8	30.0	-86.3	n/a	n/a
-HTS MIXER	-1.5	0.5	30.0	-1.5	0.5	30.0	-115.0	n/a	n/a
-HTS BPF	-0.2	0.1	40.0	-1.7	0.6	29.4	-115.1	n/a	n/a
-IF AMPL	26.0	3.0	30.0	24.3	4.2	30.0	-85.5	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	9.9	7.9	20.0	-96.2	n/a	n/a
5. IF AMP	14.0	3.0	30.0	23.9	8.0	28.5	-82.1	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	20.4	8.0	25.0	-85.6	n/a	n/a
7. CHANNELZR	-4.5	7.4	15.0	15.9	8.0	13.9	-90.1	47.5	-73.2
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-Coax	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-AMPLIFIER	12.0	3.0	30.0	10.5	4.5	30.0	-99.0	n/a	n/a
-FILTERBNK	-15.0	15.0	99.0	-4.5	7.4	15.0	-111.1	n/a	n/a
-SDLVA	0.0	0.0	99.0	-4.5	7.4	15.0	-111.1	49.3	-54.5

CHTHMIX.RFH

ESM-Everything

The Everything ESM run includes an HTS RF switched filter bank with built in BIT switch, an IF Channelizer with an HTS filterbank, and an HTS 200 nsec IF delay line. The total sensitivity and dynamic range of the two receiver paths is about -77 dBm and 50 dB respectively. A typical ESM receiver can be expected to have a noise figure on the order of 15 dB whereas the Everything run indicates a noise figure of only about 6 dB.

NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
. FRONT-END	16.3	3.8	25.0	15.3	4.8	25.0	-93.9	n/a	n/a
-BIT SWITCH	-0.2	0.1	40.0	-0.2	0.1	40.0	-114.1	n/a	n/a
-SWFILTERS	-1.0	0.3	40.0	-1.2	0.4	36.5	-114.8	n/a	n/a
-RF AMPL	17.5	3.0	25.0	16.3	3.8	25.0	-93.9	n/a	n/a
. FREQ CONV	7.0	11.0	26.5	22.3	5.3	25.4	-86.4	n/a	n/a
-MIXER	-7.0	7.0	15.0	-7.0	7.0	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-8.0	8.0	14.0	-114.0	n/a	n/a
-IF AMPL	15.0	3.0	30.0	7.0	11.0	26.5	-96.0	n/a	n/a
. LONG RUN	-10.0	10.0	99.0	12.3	5.4	15.4	-96.3	n/a	n/a
. IF AMP	12.0	3.0	30.0	24.3	5.4	25.5	-84.3	n/a	n/a
. PWR SPLIT	-3.5	3.5	99.0	20.8	5.4	22.0	-87.8	n/a	n/a
. Divider	n/a	n/a	n/a	20.8	5.4	22.0	n/a	n/a	n/a
. CHANNELZR	1.5	5.7	23.9	22.3	5.5	20.7	-86.2	50.5	-77.4
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF CABLE	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-AMPLIFIER	9.0	4.0	30.0	7.5	5.5	30.0	-101.0	n/a	n/a
-FILTERBNK	-6.0	2.5	40.0	1.5	5.7	23.9	-106.8	n/a	n/a
-SDLVA	0.0	0.0	99.0	1.5	5.7	23.9	-106.8	55.2	-60.5
. DELAY LINE	-3.6	1.3	40.0	17.2	5.4	18.4	-91.4	n/a	n/a
-200 NSEC	-3.6	1.3	40.0	-3.6	1.3	40.0	-116.3	n/a	n/a
. NB RCVR	4.5	16.5	22.0	21.7	6.4	19.4	-85.9	49.5	-76.6
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF COAX	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-1ST MIXER	-7.0	7.0	15.0	-8.5	8.5	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-9.5	9.5	14.0	-114.0	n/a	n/a
-1ST IF	11.0	5.3	30.0	1.5	14.8	23.8	-97.7	n/a	n/a
-2ND MIXER	-7.0	7.0	15.0	-5.5	15.2	12.8	-104.3	n/a	n/a
-BPF	-1.0	1.0	99.0	-6.5	15.3	11.8	-105.2	n/a	n/a
-2ND IF	11.0	5.3	30.0	4.5	16.5	22.0	-93.0	n/a	n/a
-DLVA	0.0	0.0	99.0	4.5	16.5	22.0	-93.0	53.4	-62.6

EVERY.RFH

ESM-Everything with Reduced Gain

The Everything ESM run includes an HTS RF switched filter bank with built in BIT switch, an IF Channelizer with an HTS filter bank, and an HTS 200 nsec IF delay line. The total sensitivity and dynamic range of the two receiver paths was about -77 dBm and 50 dB respectively. In many applications the need for dynamic range exceeds that of sensitivity. The table presented below shows the predicted TTDR and sensitivity as the RF amplifier gain is decreased. The attached print out shows the ADRATS results for an RF amplifier Gain of 10 dB. Runs were also made with various IF amplifier gains but the RF amplifier was found to be the major driver.

RF Gain(dB)	Sensitivity(dBm)		Dynamic Range(TTDR, dB)	
	Channelizer	NBR	Channelizer	NBR
17.5(REF)	-77.4	-76.6	50.5	49.5
15.0	-76.2	-75.2	51.4	50.3
12.5	-74.6	-73.4	52.0	50.7
10.0**	-72.6	-71.3	52.3	51.0
8.0	-70.8	-69.5	52.5	51.1

** Selected gain on print out

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EVERYTHING-REDUCED GAIN

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| NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-1.0	1.0	99.0	-1.0	1.0	99.0	-114.0	n/a	n/a
2. FRONT-END	8.8	3.8	25.0	7.8	4.8	25.0	-101.4	n/a	n/a
-BIT SWITCH	-0.2	0.1	40.0	-0.2	0.1	40.0	-114.1	n/a	n/a
-SWFILTERS	-1.0	0.3	40.0	-1.2	0.4	36.5	-114.8	n/a	n/a
-RF AMPL	10.0	3.0	25.0	8.8	3.8	25.0	-101.4	n/a	n/a
3. FREQ CONV	7.0	11.0	26.5	14.8	7.0	25.4	-92.2	n/a	n/a
-MIXER	-7.0	7.0	15.0	-7.0	7.0	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-8.0	8.0	14.0	-114.0	n/a	n/a
-IF AMPL	15.0	3.0	30.0	7.0	11.0	26.5	-96.0	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	4.8	7.2	15.4	-102.0	n/a	n/a
5. IF AMP	12.0	3.0	30.0	16.8	7.5	25.5	-89.7	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	13.3	7.5	22.0	-93.2	n/a	n/a
7. Divider	n/a	n/a	n/a	13.3	7.5	22.0	n/a	n/a	n/a
8. CHANNELZR	1.5	5.7	23.9	14.8	7.6	20.7	-91.6	52.3	-72.6
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF CABLE	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-AMPLIFIER	9.0	4.0	30.0	7.5	5.5	30.0	-101.0	n/a	n/a
-FILTERBNK	-6.0	2.5	40.0	1.5	5.7	23.9	-106.8	n/a	n/a
-SDLVA	0.0	0.0	99.0	1.5	5.7	23.9	-106.8	55.2	-60.5
9. DELAY LINE	-3.6	1.3	40.0	9.7	7.5	18.4	-96.8	n/a	n/a
-200 NSEC	-3.6	1.3	40.0	-3.6	1.3	40.0	-116.3	n/a	n/a
10. NB RCVR	4.5	16.5	22.0	14.2	10.1	19.4	-89.7	51.0	-71.3
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-65.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF COAX	-1.5	1.5	99.0	-1.5	1.5	99.0	-114.0	n/a	n/a
-1ST MIXER	-7.0	7.0	15.0	-8.5	8.5	15.0	-114.0	n/a	n/a
-BPF	-1.0	1.0	99.0	-9.5	9.5	14.0	-114.0	n/a	n/a
-1ST IF	11.0	5.3	30.0	1.5	14.8	23.8	-97.7	n/a	n/a
-2ND MIXER	-7.0	7.0	15.0	-5.5	15.2	12.8	-104.3	n/a	n/a
-BPF	-1.0	1.0	99.0	-6.5	15.3	11.8	-105.2	n/a	n/a
-2ND IF	11.0	5.3	30.0	4.5	16.5	22.0	-93.0	n/a	n/a
-DLVA	0.0	0.0	99.0	4.5	16.5	22.0	-93.0	53.4	-62.6

EVERY.RFH

Dynamic Range
Considerations

Background

The future use of superconductors will be driven by the perceived difficulties associated with cryogenic refrigeration, the advances being made in low noise figure conventional devices, and the identified performance advantages of HTS devices. It is suspected that with time cryogenic cooling will become accepted as reliable and relatively low cost (i.e., less than 5K). In the past, radio astronomy was the major user of cooled receivers and the reason was lower noise figures and better sensitivity.

However, new RF amplifiers are now available with noise figures in the 2 to 3 dB range versus 4 to 6 dB just a few years ago. In most ESM applications this has meant that the primary problem has become a lack of spur free dynamic range. The first ESM type systems were crystal video detector RWR's that provided a sensitivity of about -40 dBm and a dynamic range of 40 dB. They could see the main beams of threat radar's in the presence of relatively strong signals (up to 0 dBm). Modern ESM systems are now designed to see into radar sidelobes using receiver sensitivities on the order of -70 dBm not including aperture gain. However, the spur free dynamic range has increased little (40 to 50 dB) with the result that received signals in the 0 to -20 dBm range can produce spurious signals that are improperly identified or choke processing. It is in improving ESM dynamic range that HTS is believed to have the greatest opportunity for performance improvement.

The standards for measuring spur free dynamic range is the Two Tone Dynamic Range as computed by the ADRATS program. However, this is not a fair representation in ESM systems where the RF bandwidth(s) and IF bandwidth(s) can be significantly different. A better approach is to view the TTDR and spurs from each of the three potential sources.
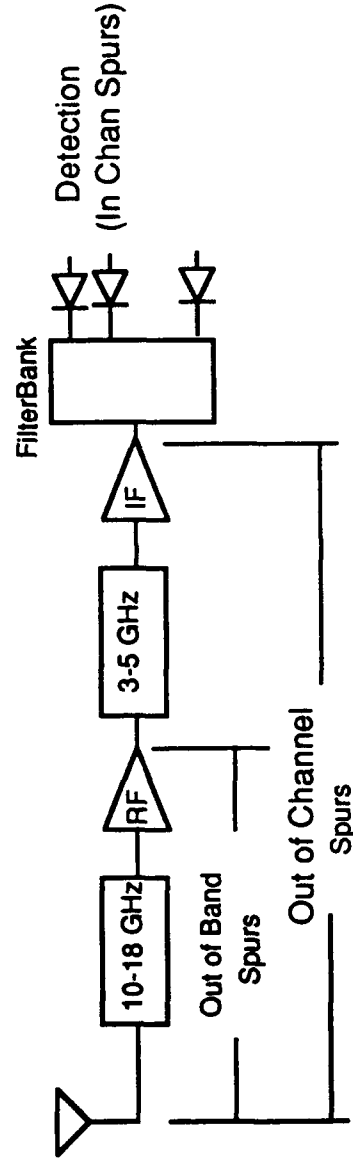
The three spur generating areas are as shown above due to the first RF non-linear devices (amplifier) that precedes setting of the IF bandwidth (3-5 GHz), the combined elements that precede the final setting of detection channelization (100 MHz), and the output of the channel filter bank. In the latter case the presence of spurs has no impact on the detection process except that the presence of two simultaneous signals, while generally known, can corrupt parameter measurements. In most cases this is the TTDR that is computed by analysis programs and spread sheets such as ADRATS. In the second case two strong out-of-channel signals present in the 3 to 5 GHz IF amplifier output can create spurs that do fall in other channels where they are detected. For a uniform signal density environment the wider the IF coverage of the channelizer filter bank the higher the probability of detecting spur even in any one given channel. The TTDR from the input to the IF amplifier output (relative to channel sensitivity) and the relative IF bandwidth (3 to 5 GHz relative to 100 MHz) are both drivers of Out-of-Channels spurs. In the third Out-of-Band case, spurs are generated by strong signals that fall outside the 2 GHz range being observed. These spur can then fall within the 2 GHz range and be detected by 100 MHz channel detectors. In this case the TTDR to the RF (amplifier) output combined with the relative RF bandwidth help determine the probability of detecting these spurs.

Lets now take another look at the baseline ESM system of the previous 2nd Run in terms of spur generation in each of the three major areas.

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Dynamic Range (Run 2)

The Run 2 Channelizer Thread IP3 is typical for most ESM system designs in that the net IP3 reflected to the input is seen to fall rapidly with box number so that back-end components tend to exhibit less impact on the final value. The reflected IP3 can be converted to TTDR using the following standard equation:

$$TTDR = 2/3 * [IP3in - Sensitivity]$$

The three previously defined zones(Out-of-Band, Out-of-Channel, and In-Channel) are identified in the Run 2 IP3 plot. For the Run 2 Channelizer Sensitivity of -72.3 dBm the computed TTDR's are as indicated in the table below. The identified Figure-of-Merit (FOM) is an attempt to relate TTDR and the relative bandwidth. Consider a uniform distribution of signal powers in dBm that varies from 0 dBm to the predicted sensitivity. Then only signals from 0 to [Sensitivity-TTDR] dBm have sufficient power to create detectable spurs. If the bandwidth is wider than desired then more spurs are generated. For example a 10 to 18 GHz input would create potential spurs from dc to 54 GHz whereas only 2 GHz is of interest. The FOM approximation for Out-of-Band spurs is as follows:

$$FOM = [(Sens-TTDR)/Sens] \times [((Bw\ RF/ Bw\ IF)-1) \times (Bw\ IF/channel)]$$
(out-of-band)

Similarly, a 2 GHz wide channelizer can create spurs that fall within the 100 MHz channelization. The combined Out-of-Channel FOM approximation is as follows:

$$FOM = [(Sens-TTDR)/Sens] \times [(Bw\ IF/channel)-1]$$
(out-of-channel)

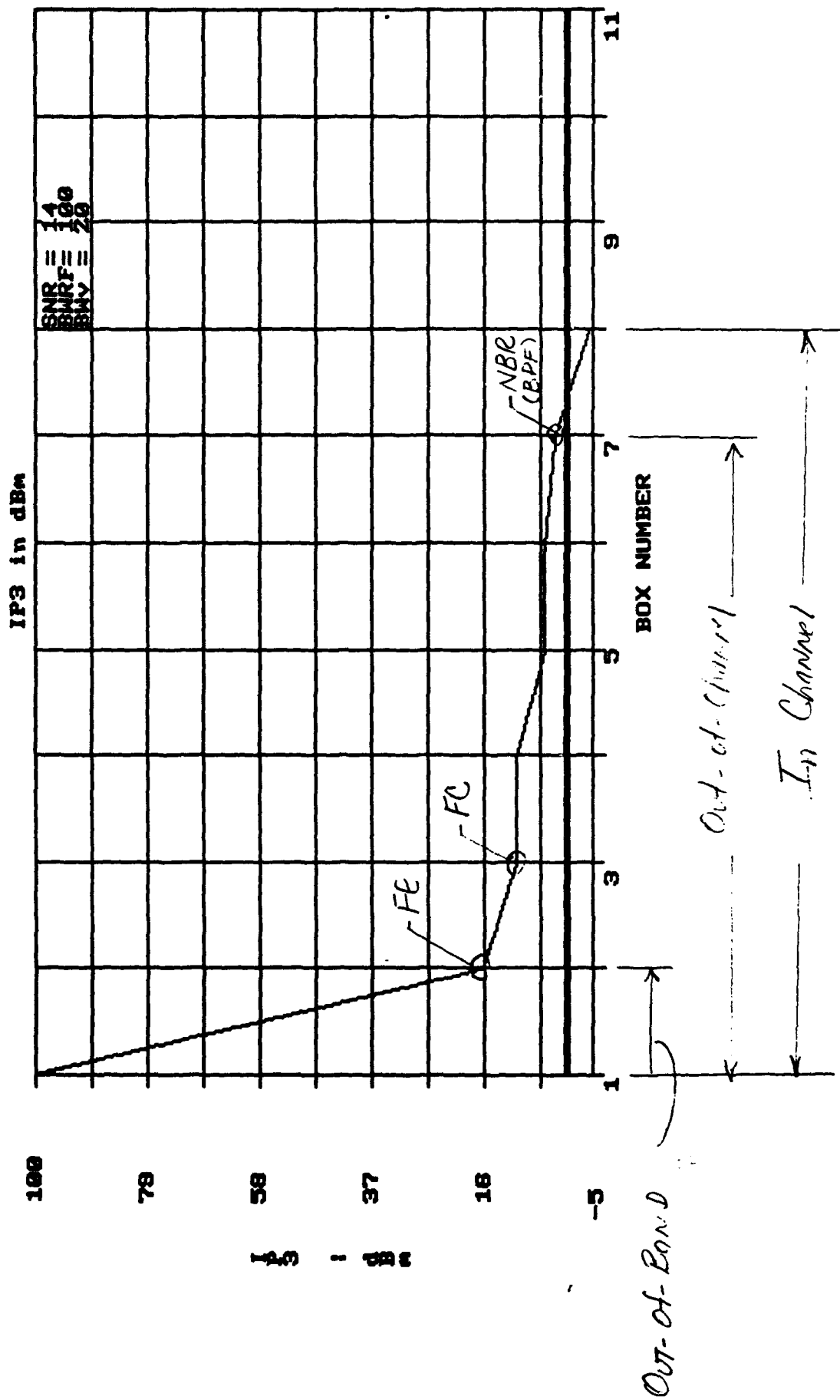| Zone	IP3in	TTDR	Bandwidth	Figure-of-Merit
Out-of-Band	15.0 dBm	58.2 dB	10 GHz	15.6
Out-of-Channel	-2.1 dBm	46.8 dB	2 GHz	6.7
In-Channel	-2.1 dBm	46.8 dB	100 MHz	n/a

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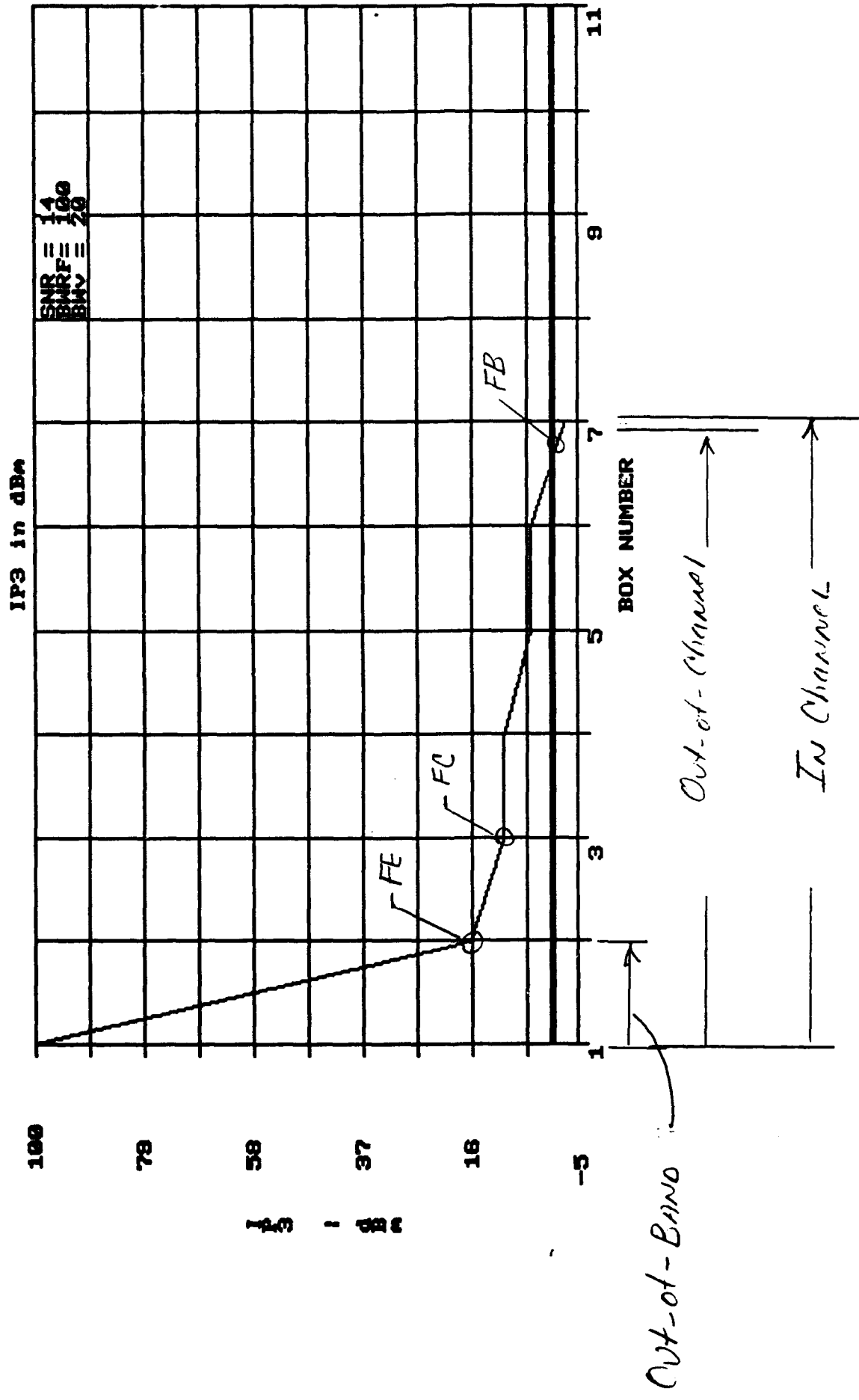
RUN 2 - CHANNELIZER 7-INPUT

Dynamic Range (Run 2 -NBR)

The Run 2 IP3 plot has been marked to identify the three dynamic range zones. Unlike the channelizer results there is now a marked difference in Out-of-Channel and In-Channel zones. The reason is that previously in the channelizer path a passive filter bank formed the channelization just in front of the detector whereas now the NBR has active amplifiers that follow the input filter that sets channel width. The results for the NBR thread are shown below. It should be noted that for a higher figure-of-merit(FOM number the greater number of interfering spurs can be expected. On this basis the table below indicates that the Out-of-Band front-end generating spurs should be of greatest concern in spite of the larger TTDR associated with this zone. It should be further noted that had the Out-of-Band bandwidth been reduced to 2 GHz to match the IF bandwidth the FOM would reduce to 0. The additional spurs associated with the Out-of-Channel zone is inherent with the use of channelized receivers to improve probability-of-detection. If a single channel or superhet receiver was employed with RF and IF filters that matched the channel width of 100 MHz, then the Out-of-Channel FOM would also reduce to 0. Only the In-channel TTDR would result in spur generation and, as previously indicated, these spurs are in the same channel as the strong signals and will not cause new false detections.

Zone	IP3in	TTDR	Bandwidth	Figure-of-Merit
Out-of-Band	15.0 dBm	57.0 dB	10 GHz	15.3
Out-of-Channel	2.3 dBm	48.5 dB	2 GHz	5.9
In-Channel	-4.1 dBm	44.3 dB	100 MHz	n/a

IP3 in dBm

SNR = 14
BWRF = 100
BWV = 20

NBR (B.P.F)

FC

FE

BOX NUMBER

Out-of-Channel

In Channel

1   3   5   7   9   11

100
79
58
37
16
-5

IP3 - dBm

Out-of-Band

RUN 2 - NBR INPUT

ESM-Channelizer Single Tone Dynamic Range

There are two types of dynamic range commonly referred to by RF designers: two tone or spur free dynamic range and single tone dynamic range. Prior discussion and analysis has been for TTDR relative to sensitivity. It should be noted that designer of RF amplifiers and other components compute TTDR relative to their noise floor generally yielding a TTDR that can be 10 dB higher than a TTDR relative to a sensitivity based on a 15 dB SNR. Some receiver manufacturers have also been seen to use this definition to inflate their TTDR results. Single tone dynamic range definitions also vary with the most common receiver definition being from the maximum input power causing 1 dB compression somewhere within the receiver to the minimum signal or threshold sensitivity level.

The STDR results for the 2nd Run Channelizer has been computed by ADRATS and found to be 56.3 dB (for SDLVA that can operate with input powers up to 0 dBm). The Psig column indicates the power at each box output for a o dBm at the system or Box 1 input. The asterisk identify those power outputs that exceed the box limit (saturation). The 56.3 dB STTD implies that (sens-STDR) the maximum system input signal level is -26 dBm. It should be noted that the net gain to the SDLVA is 16 dB with a max input limit of 0 dBm or making the gain to the channelizer 20.5 dB with a max input of +4.5 dBm.

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ESM-2ND RUN CHANNEL STDR

BLOCK NO/TITLES	Gain (nom)	NF (dB)	Nd dBm/MHz	RFBW MHz	IP3 (dBm)	P1dB (dBm)	Psig (dBm)
1 ANT CABLE	-1.0	1.0	-114.0	10000.0	99.0	99.0	-1.0
2 FRONT-END	10.0	8.0	-96.0	10000.0	25.0	10.0	9.0
3 FREQ CONV	7.0	11.0	-88.3	10000.0	26.5	7.0	16.0*
4 LONG RUN	-10.0	10.0	-98.2	10000.0	99.0	99.0	6.0
5 IF AMP	18.0	3.0	-80.1	10000.0	30.0	20.0	24.0*
6 PWR SPLIT	-3.5	3.5	-83.6	10000.0	99.0	99.0	20.5
7 CHANNELZR	-4.5	7.4	-88.0	100.0	15.0	4.5	16.0*
TOTALS:	16.0	10.0			13.9		

RF Bandwidth(MHz)=   100.0
Video Bandwidth(MHz)=   20.0
Detector Tss(dBm)=   -65.0
-- Det Video BW(MHz)=   20.0
Sensitivity(dBm) =   -72.3
Two Tone Dynamic Range(dB) =   46.8
Single Tone Dynamic Range(dB) = 56.3

(ESMCH.RFH)

ESM-NBR Single Tone Dynamic Range

The STDR of the 2nd Run NBR thread is 45.5 dB which is significantly less than the 56.3 dB of the Channelizer thread. The reason for this difference is the much higher total gain of the NBR thread (25 dB vs 16 dB). In both threads it is the back-end detector and it's maximum input signal limit that is controlling STDR. It is interesting to note that had the max input signal of the detector's been increased to very high values that the STDR of the NBR thread would have increased to 50 dB and the Channelizer thread would have went clear up to 64 dB.

ESM-2ND RUN NBR STDR

BLOCK NO/TITLES	Gain (nom)	NF (dB)	Nd dBm/MHz	RFBW MHz	IP3 (dBm)	P1dB (dBm)	Psig (dBm)
1 ANT CABLE	-1.0	1.0	-114.0	10000.0	99.0	99.0	-1.0
2 FRONT-END	10.0	8.0	-96.0	10000.0	25.0	10.0	9.0
3 FREQ CONV	7.0	11.0	-88.3	10000.0	26.5	7.0	16.0*
4 LONG RUN	-10.0	10.0	-98.2	10000.0	99.0	99.0	6.0
5 IF AMP	18.0	3.0	-80.1	10000.0	30.0	20.0	24.0*
6 PWR SPLIT	-3.5	3.5	-83.6	10000.0	99.0	99.0	20.5
7 DELAY LINE	0.0	30.5	-80.5	10000.0	27.0	0.0	20.5*
8 NBR	4.5	16.5	-75.9	100.0	22.0	-4.5	25.0*
TOTALS:	25.0	13.1			20.9		

RF Bandwidth(MHz)=   100.0
Video Bandwidth(MHz)=   20.0
Detector Tss(dBm)=   -65.0
-- Det Video BW(MHz)=   20.0
Sensitivity(dBm)   =   -70.5
Two Tone Dynamic Range(dB)   =   44.2
Single Tone Dynamic Range(dB) =   45.5

(ESMNBR.RFH)

Future Candidates For
# HTS Inclusion

ESM-Future HTS Candidates
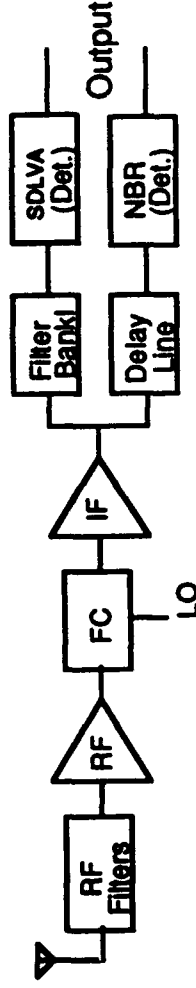
Example ESM System

The above example conventional ESM system has quadruplexer filters at the front-end that separate frequency into octave or less bandwidths. However, these bandwidths can be as large as 10 GHz (10 to 18 GHz) which is five times wider than the selected IF bandwidth of 2 GHz (3 to 5 GHz). We have previously noted that the HTS FTSW can provide matching RF bandwidths at modest and generally acceptable insertion loss particularly when the BIT/Cal switch is incorporated into the device. We have also looked at HTS delay lines, IF filter banks and even frequency converters.

The need for a cooler associated with any HTS component may drive the architecture toward even greater use of HTS components that can share coolers. In the future this may even drive designs toward a total HTS architecture.

Future ESM System Architecture

HTS Cooler: Filter Bank → Detector → Video LPF → A/D → Processor
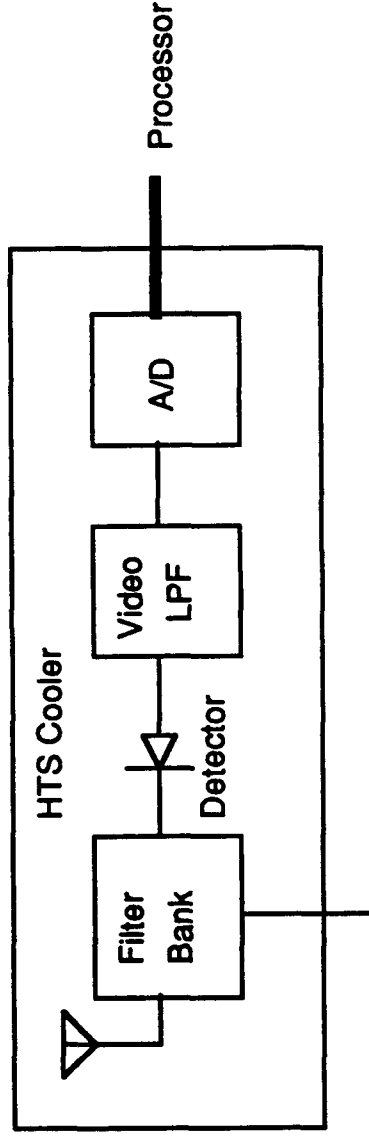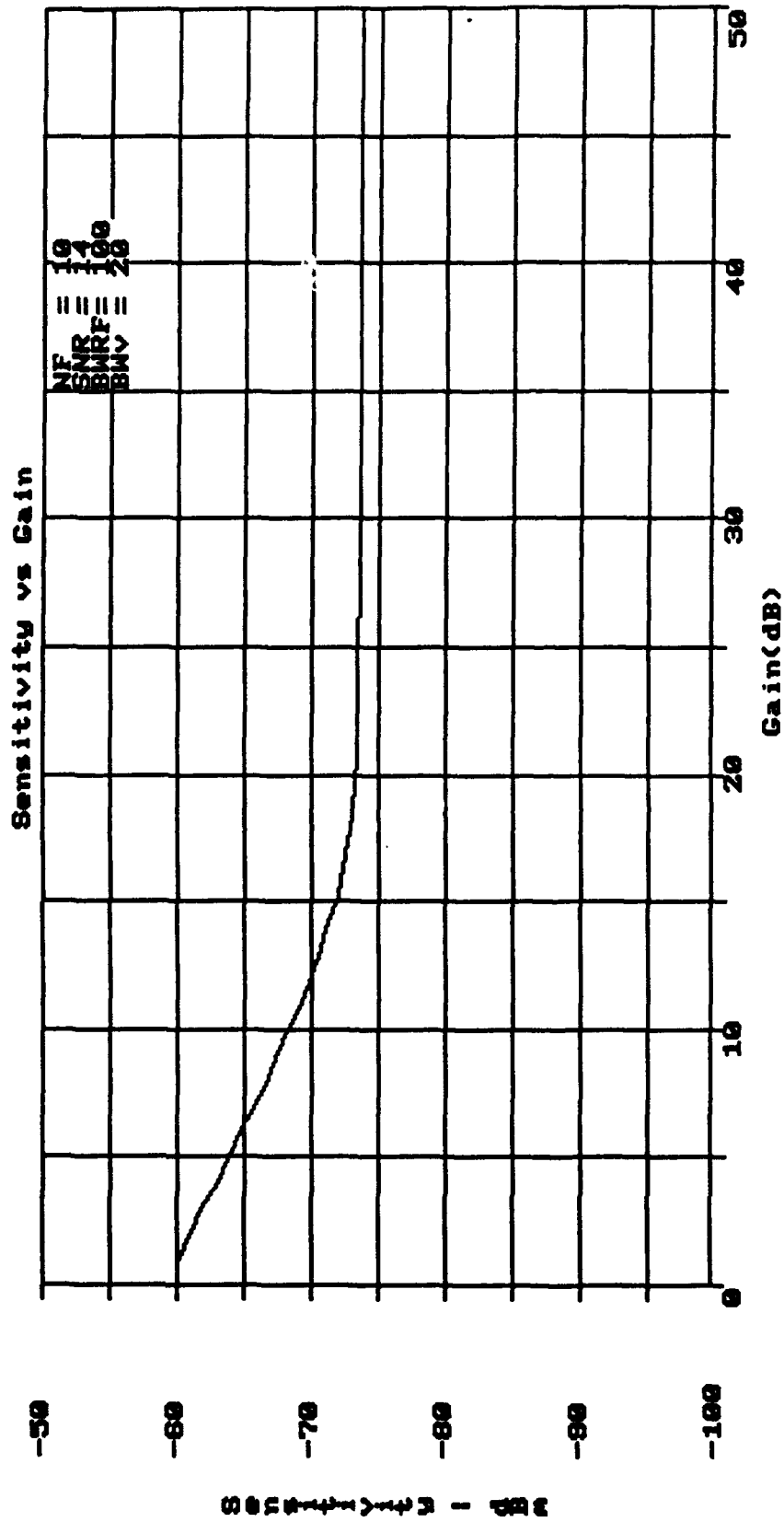
Totally Passive HTS Architecture (No Amplifiers)

A total HTS ESM architecture can be based on significant improvements in the detector tangential sensitivity(Tss) that removes the need for front-end amplification and the associated limits on dynamic range. A typical conventional RF detector has a Tss of -50 dBm in a 2 MHz video bandwidth. The Shewchun and Marsh article (p115 of SPIE vol 1477) would appear to indicate that an HTS detector with a -64 dBm TSS in a 2 MHz is possible today and better units can be expected in the future. The Following set of eight curves show the gain required to reach the knee of both sensitivity and dynamic range curves as a function of the detector Tss. It should be noted that conventional SDLVA's are also available with a Tss -75 dBm or better. However, these are typically active IF devices with limited RF bandwidths. They also exhibit relatively poor IP3's but since the bandwidth is established prior to the detector, the in-channel spurs being generated are of little concern.
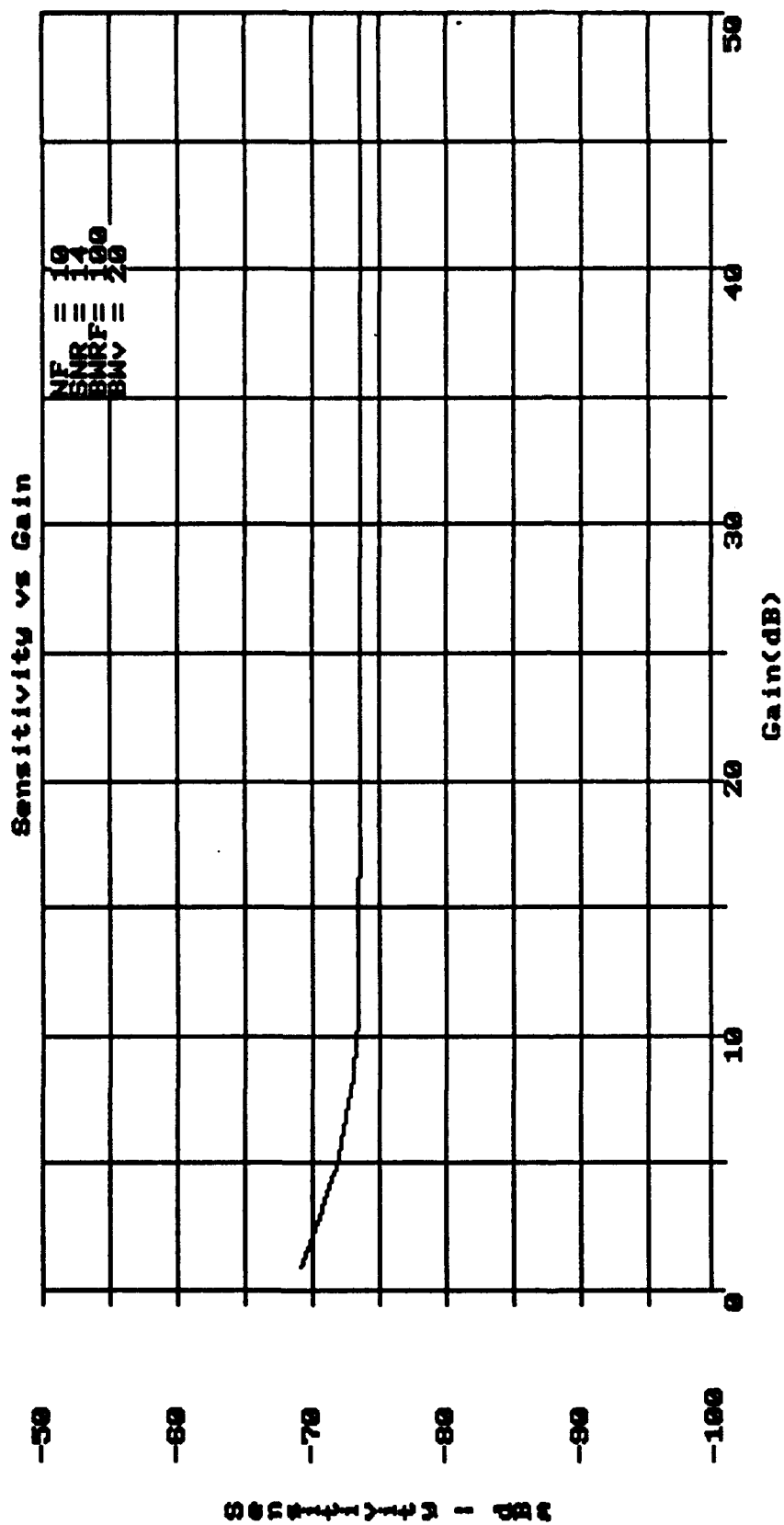
An area of greater concern is the RF filter bank that is now viewed as a stepped channelizer at RF (i.e., 100 MHz) with each channel having a detector and low pass filter(LPF) associated with it. This is certainly far in the future.
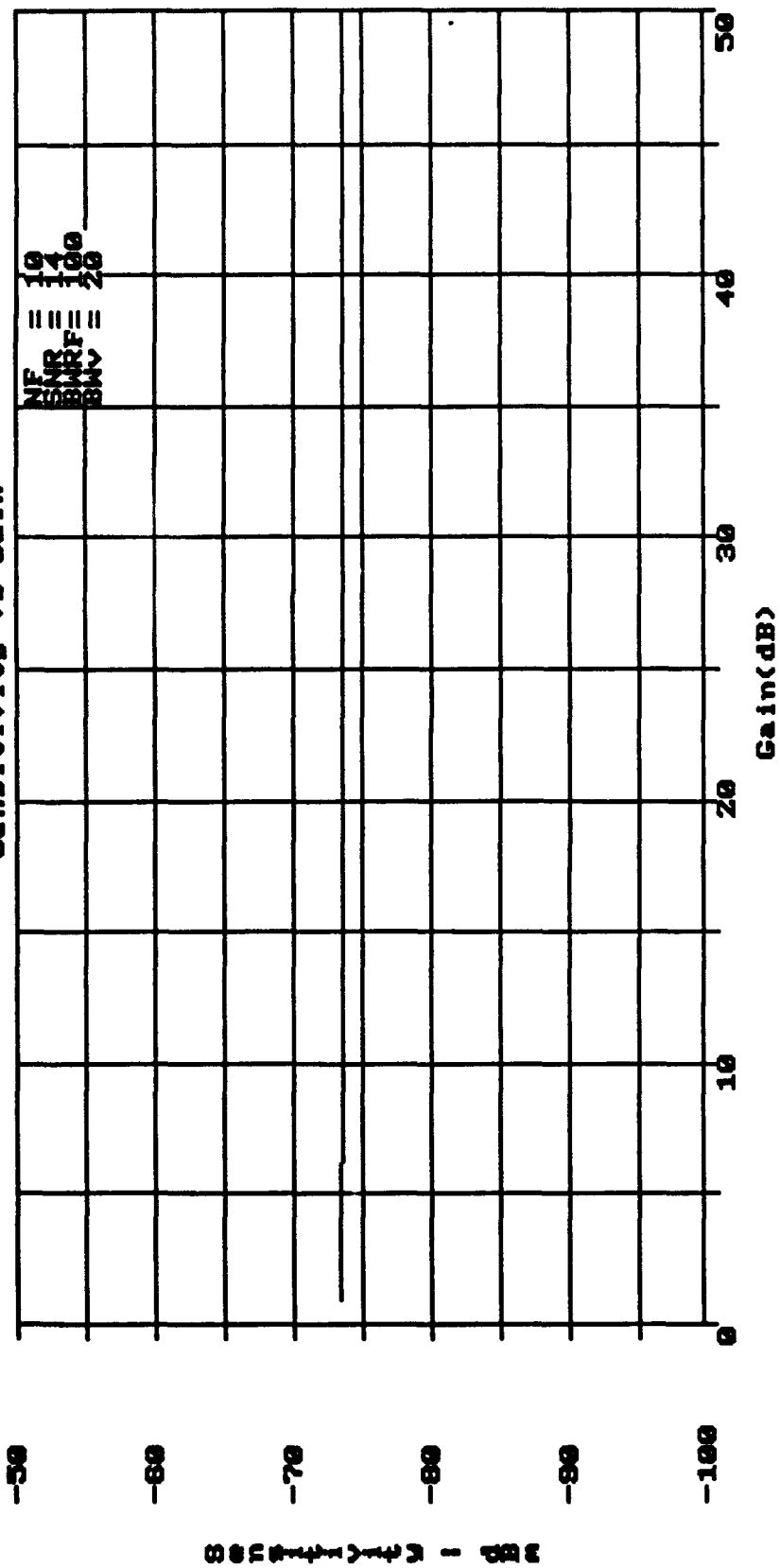
Sensitivity vs Gain

NF   = 10
SNR   = 14
BWRF = 100
BW   = 20

Gain(dB)

dB - Sensitivity

$\overline{I}_{SS\ DET} = -55\ dB_{,,}$

Sensitivity vs Gain

NF   = 10
SNR   = 14
BWRF   = 100
BW   = 20

Gain(dB)

dB - Sensitivity
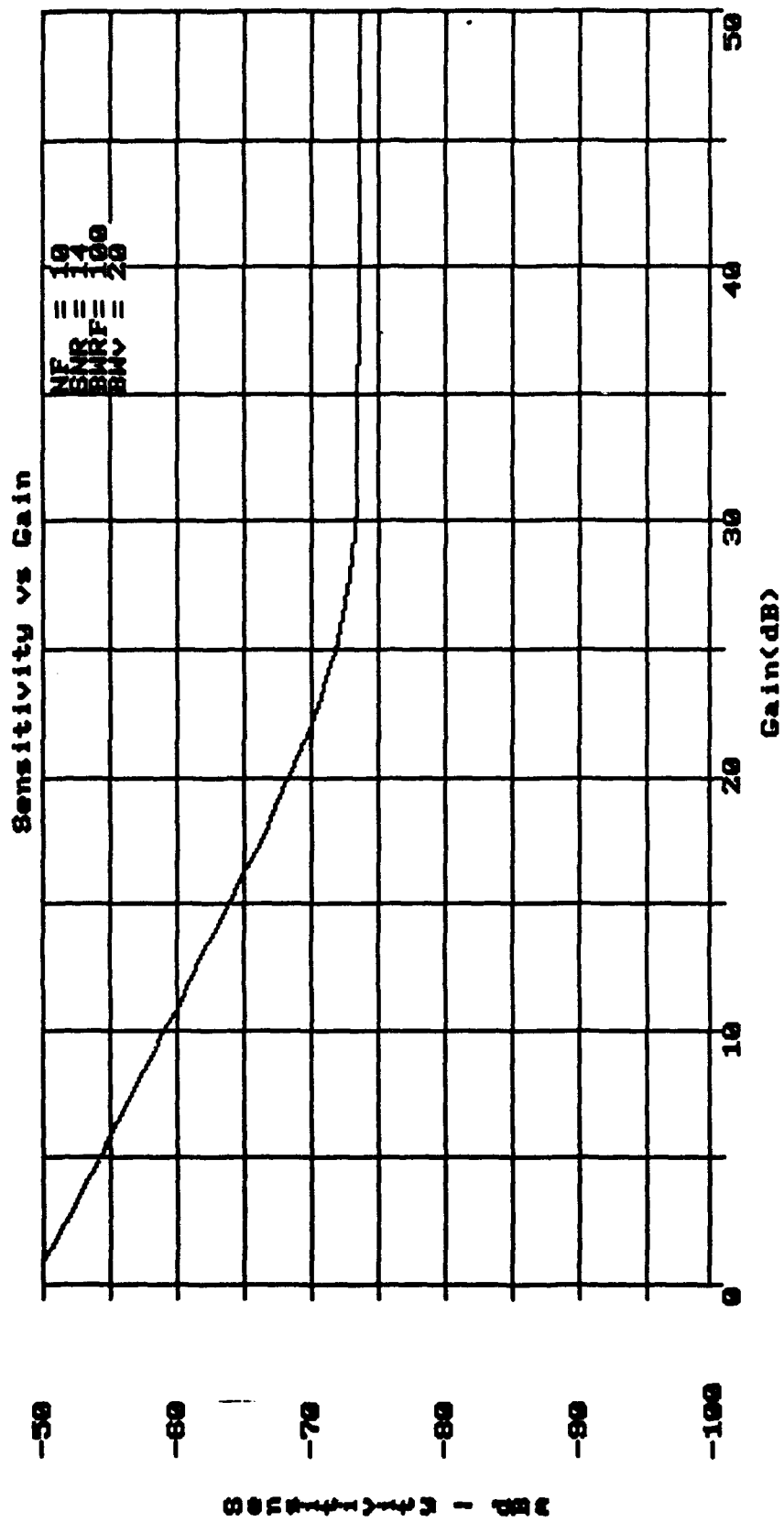
$I_{SS\,DET} = -65\,dB_{,,}$

Sensitivity vs Gain

$T_{SS \, DET} = -75 \, dB\text{''}$

Sensitivity vs Gain

NF = 10
SNR = 14
BWRF = 100
BWV = 20

Sensitivity — dBm

-50
-60
-70
-80
-90
-100

0   10   20   30   40   50

Gain(dB)

Iss DET = -85 dBm

Two Tone Dynamic Range vs Gain
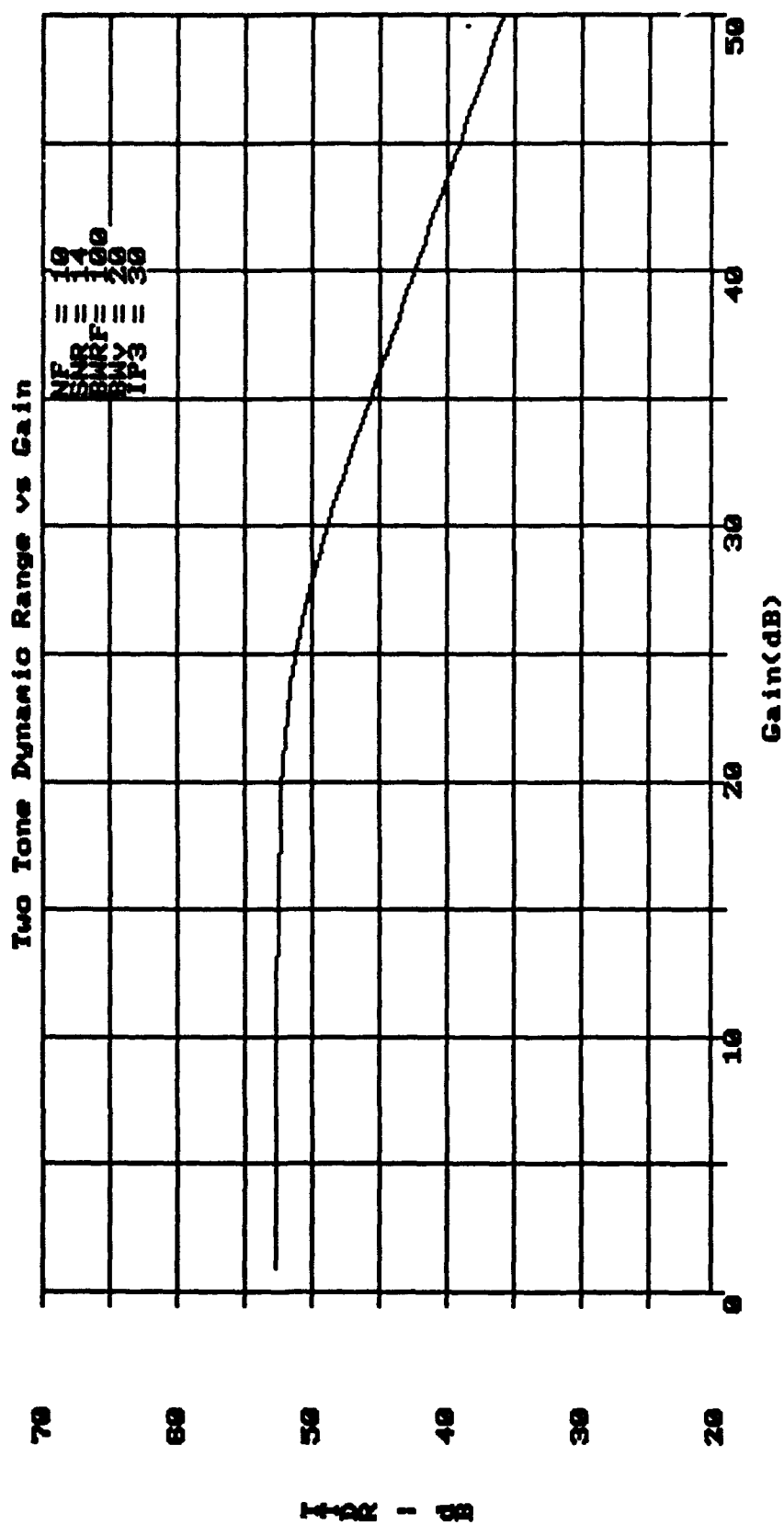
$T_{SS} DET = -55 dB_m$

Two Tone Dynamic Range vs Gain

NF   = 10
BNR   = 14
BWRF   = 100
BWV   = 200
IIP3   = 30

Gain(dB)

TDR - dB

$T_{SS\,DET} = -65\,dB_{,,}$

Two Tone Dynamic Range vs Gain

NF   = 10
?NR = 14
BWRF = 100
BWV = 200
IP3 = 30

HHDR - dB

70
60
50
40
30
20

Gain(dB)

0   10   20   30   40   50

$T_{SS\ DET} = -75\ dB$))

Two Tone Dynamic Range vs Gain

NF   = 10
SNR   = 14
BWRF   = 100
BW   = 200
IIP3   = 30

Gain(dB)
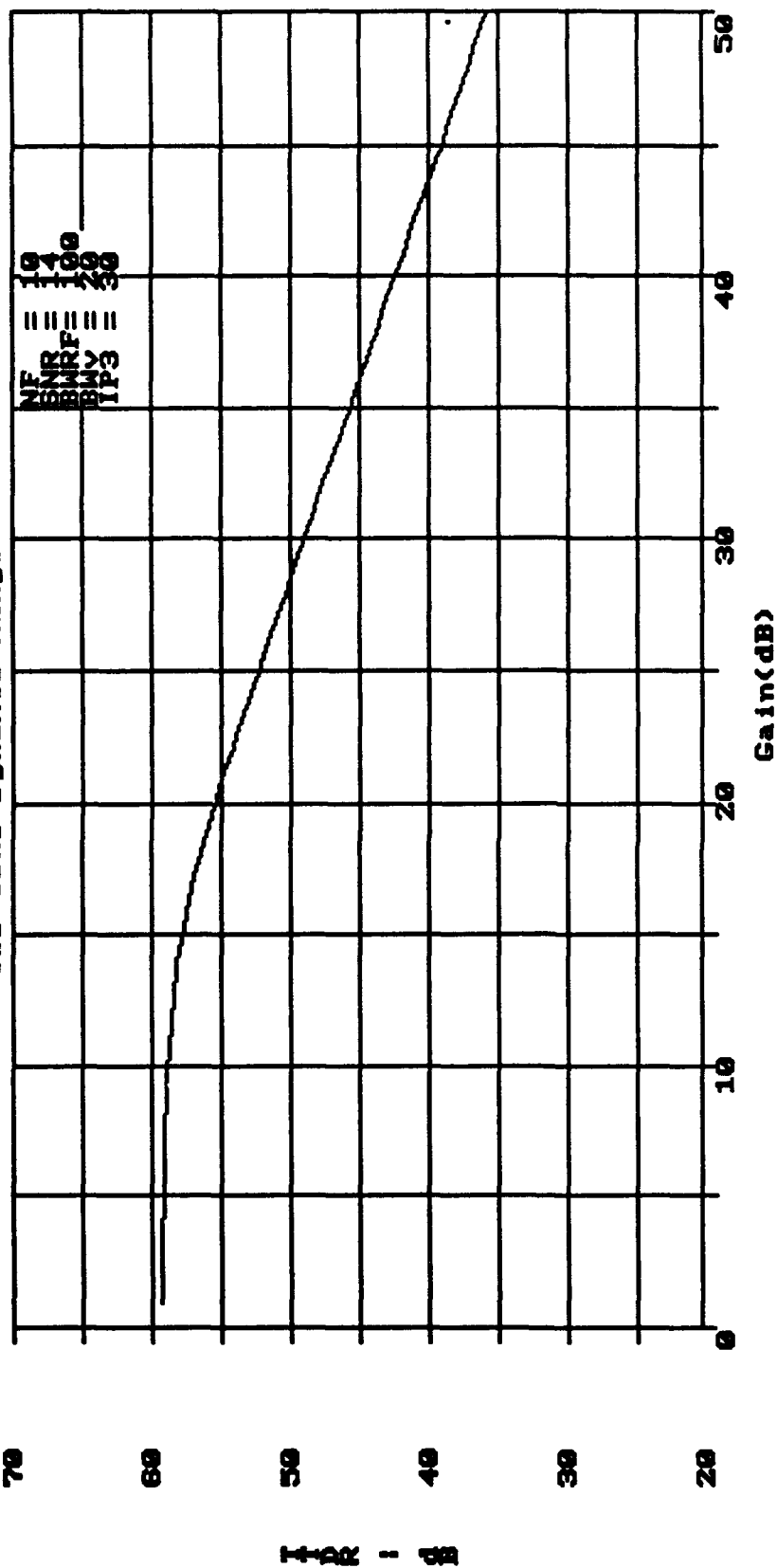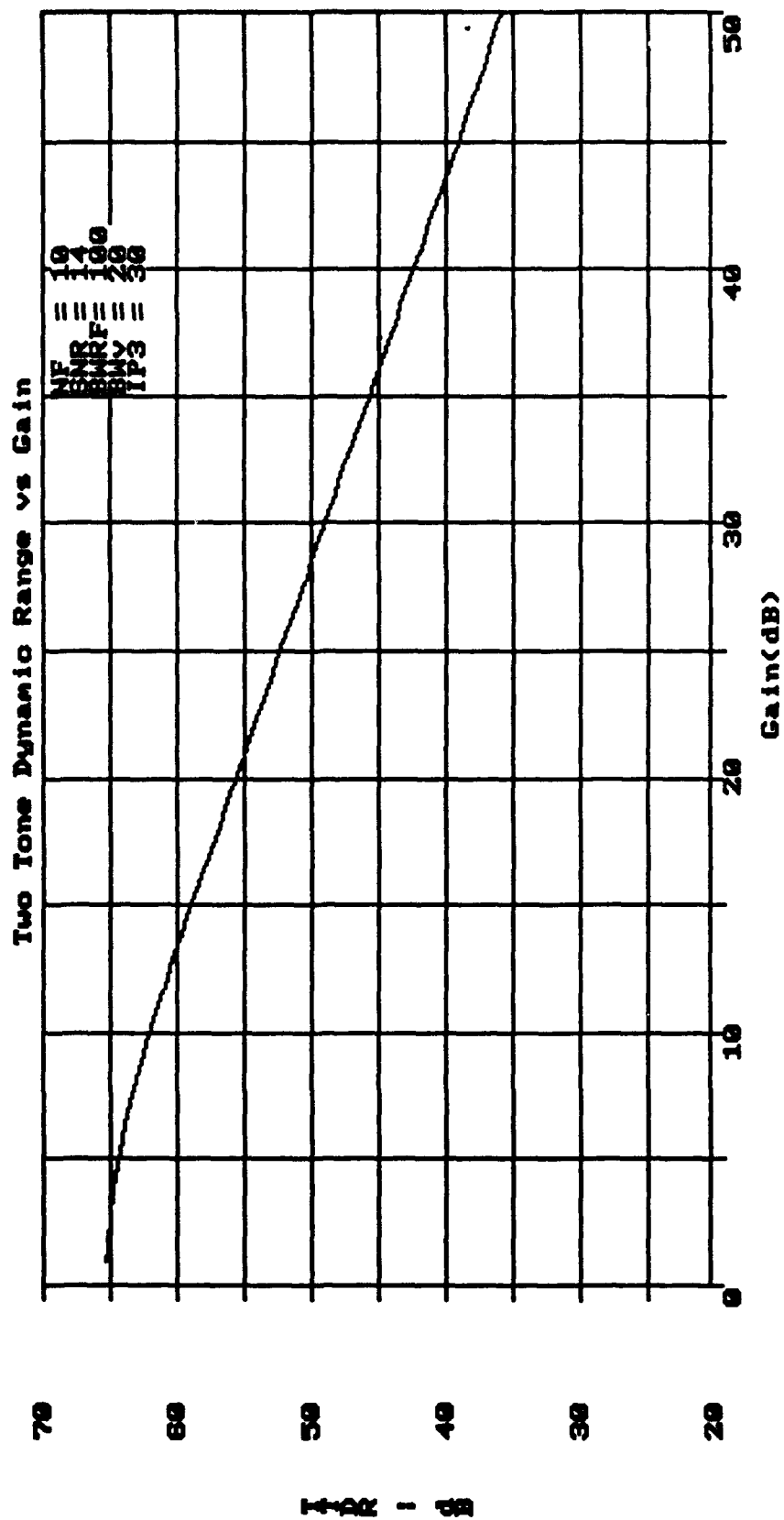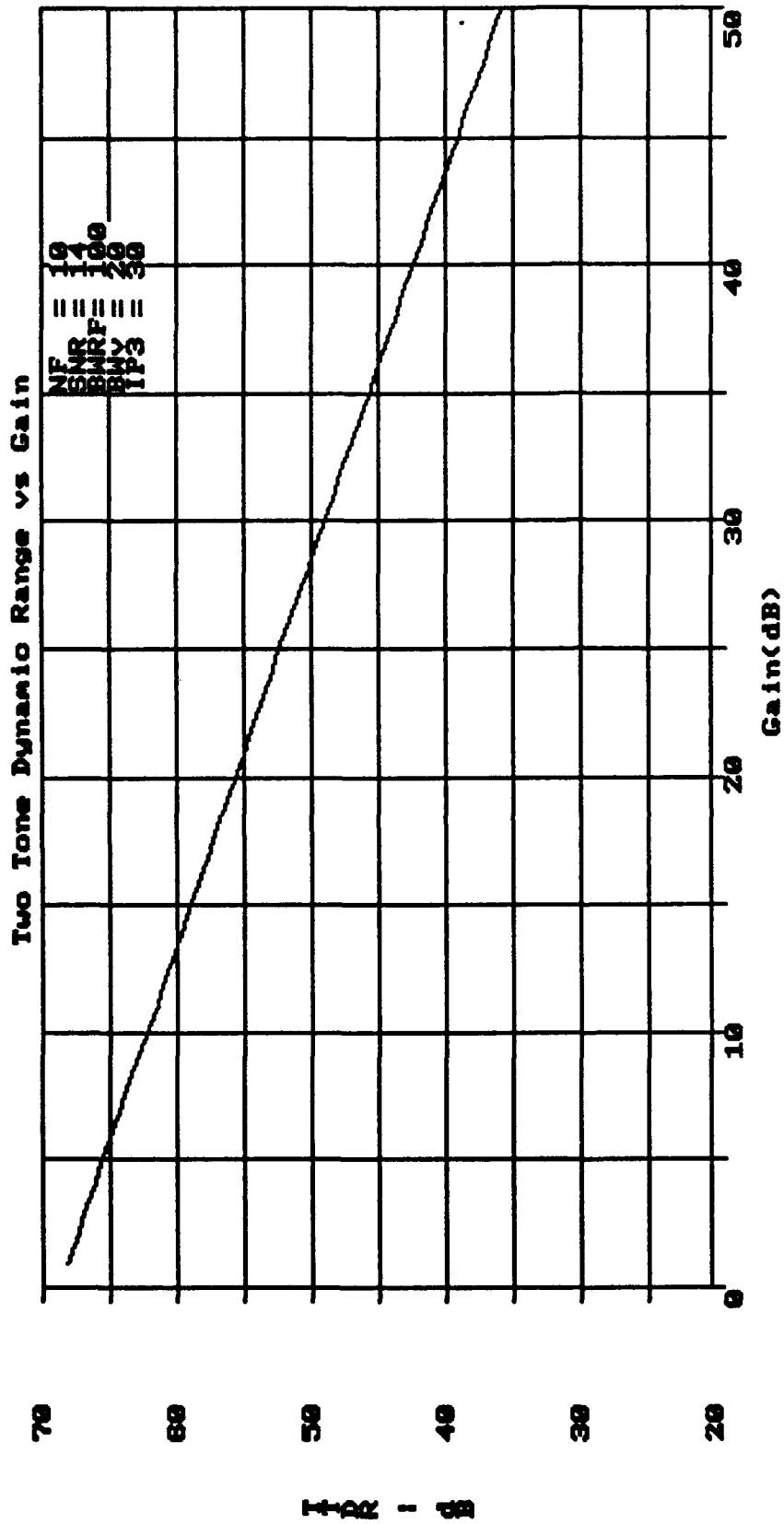
$T_{SS\,DET} = -85\ dB,$

Radar / ESM Shared Aperture

The shared aperture shown above is based on use of a "segmented aperture" that uses most of the array elements to form the sum and delta beams needed for high gain operation while reserving a few elements with proper spacing for interferometery. (Note: It is unlikely using today's technology that a radar array can be fabricated to cover the 2 to 18 GHz range desired by an ESM system. However, it is certainly possible to cover a significant bandwidth now and more in the future.) The resulting system can operate as a scanning high gain wide band acquisition ESM system capable of sidelobe detection, a conventional low gain ESM system for rapid acquisition of mainbeam emitters, a set-on high gain update system that can update trackers using sidelobe measurements, and as a conventional radar.

In the high gain modes the array aperture elements are sent to the beam forming networks that form the sum and difference patterns associated with monopulse radar operation. An HTS FTSF isolates the selected radar frequency (narrow band/tuned resonator channels) and passes all other RF. The sum signal is sent through a 2 GHz switched filter bank to a wide band IFM based receiver that monitors the sum channel and ,upon detection, steers a set of NBR's or superhets to the frequency detected. A set of HTS delay lines makes this cued RF approach possible. It should be noted that signal density would normally prevent an IFM from being used in such an application. However, the combination of the RF thinning provided on an as needed basis by the HTS switched filter bank, the spatial filtering provided by the high gain array, and threshold control can reduce the density to manageable levels. In a low density environment the shared aperture could spatially scan while the wide open wide band IFM cued NBR receiver combination passively detected and measured parameters of signals including AOA within the RF frequency range. The range to the detected emitter could be determined using either passive triangulation or active radar.

The high gain scan described above would permit an emitter to be detected that never pointed his beam at you. Searching a dense environment in both frequency and space can be a lengthy process. Another important ESM case is the modern phased array short on-time emitter that can paint a target, locate it and not return for a relatively long period of time. In this case the 3 to 5 GHz Channelized receiver can be used to detect the main beam, measure it's key parameters including angle-of-arrival (AOA), and commence tracking. Future tracking updates can then be obtained by steering the high gain array to measure emitter sidelobes.
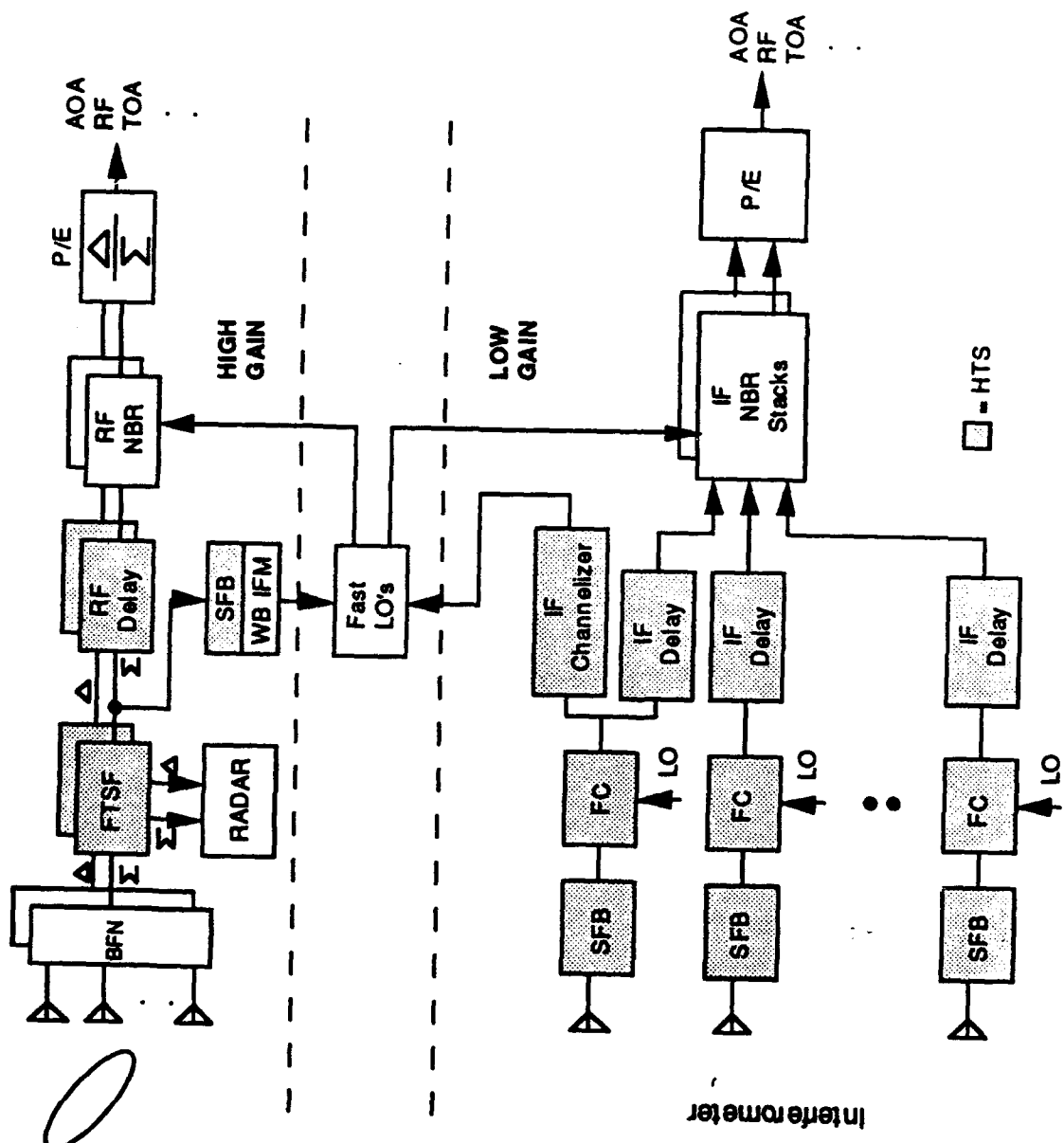
Radar / ESM Shared Aperture
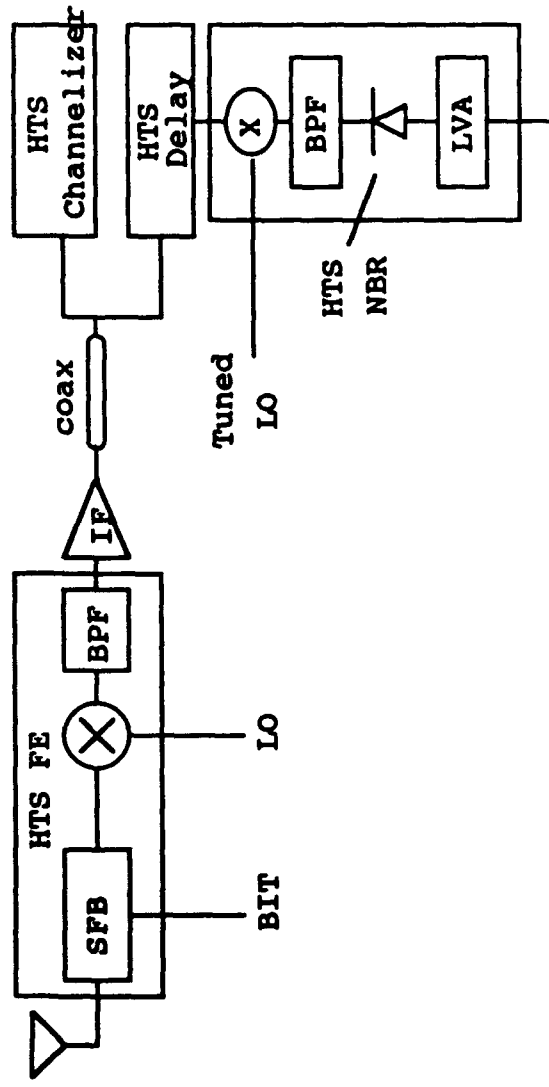
Future ESM System

The Future ESM System shown above uses an HTS front-end with a conventional low noise figure IF amplifier that provides all the gain needed. At the back end an HTS filter bank and HTS detectors form a channelizer. Similarly, the cued path employs an HTS delay line and an HTS narrow band receiver(NBR). The NBR also employs an HTS detector diode followed by an HTS video filter. A log video amplifier is shown as part of the HTS NBR but could also be of conventional design. The performance estimated for this combination of HTS devices is shown in the attached print out. The two path both show a sensitivity of about -75 dBm and a dynamic range of about 56 dB. Compared to the 2nd run reference this is about a 3 to 4 dB improvement in sensitivity and about a 10 dB improvement in dynamic range

FUTURE ESM

NAME	COMPONENTS			TOTALS				RECEIVERS	
	GAIN (dB)	NF (dB)	IP3 (dBm)	GAIN (dB)	NF (dB)	IP3 (dBm)	NOISE (dBm/MHz)	2TDR (dB)	SENS (dBm)
1. ANT CABLE	-0.2	0.2	99.0	-0.2	0.2	99.0	-114.0	n/a	n/a
2. FRONT-END	-1.2	0.4	36.5	-1.4	0.6	36.5	-114.8	n/a	n/a
-BIT SWITCH	-0.2	0.1	40.0	-0.2	0.1	40.0	-114.1	n/a	n/a
-SWFILTERS	-1.0	0.3	40.0	-1.2	0.4	36.5	-114.8	n/a	n/a
3. FREQ CONV	18.3	4.2	29.6	16.9	5.3	29.6	-91.8	n/a	n/a
-MIXER	-1.5	0.5	20.0	-1.5	0.5	20.0	-115.0	n/a	n/a
-BPF	-0.2	0.1	40.0	-1.7	0.6	19.8	-115.1	n/a	n/a
-IF AMP	20.0	3.0	30.0	18.3	4.2	29.6	-91.5	n/a	n/a
4. LONG RUN	-10.0	10.0	99.0	6.9	5.5	19.6	-101.6	n/a	n/a
5. IF AMP	10.0	3.0	30.0	16.9	5.8	26.8	-91.3	n/a	n/a
6. PWR SPLIT	-3.5	3.5	99.0	13.4	5.8	23.3	-94.8	n/a	n/a
7. Divider	n/a	n/a	n/a	13.4	5.8	23.3	n/a	n/a	n/a
8. CHANNELZR	-6.5	3.0	37.0	6.9	5.9	16.7	-101.2	56.3	-74.6
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-75.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF CABLE	-0.5	0.5	99.0	-0.5	0.5	99.0	-114.0	n/a	n/a
-FILTERBNK	-6.0	2.5	40.0	-6.5	3.0	40.0	-117.5	n/a	n/a
-HTS DETECT	0.0	0.0	40.0	-6.5	3.0	37.0	-117.5	70.6	-62.5
9. DELAY LINE	-3.6	1.3	40.0	9.8	5.8	19.6	-98.4	n/a	n/a
-200 NSEC	-3.6	1.3	40.0	-3.6	1.3	40.0	-116.3	n/a	n/a
10. NB RCVR	-2.2	1.1	19.7	7.6	5.9	15.4	-100.5	55.2	-75.0
(BWrf= 100.0 ,BWv= 20.0 ,TSSd=-75.0 ,BWdet= 20.0 ,Eq=Linear ,SNR= 14)									
-IF COAX	-0.5	0.5	99.0	-0.5	0.5	99.0	-114.0	n/a	n/a
-HTS SSBMIX	-1.5	0.5	20.0	-2.0	1.0	20.0	-115.0	n/a	n/a
-HTS BPF	-0.2	0.1	40.0	-2.2	1.1	19.8	-115.1	n/a	n/a
-HTS DETECT	0.0	0.0	40.0	-2.2	1.1	19.7	-115.1	59.1	-66.7

future.RFH

HTS Conclusions

High Temperature Superconductor(HTS) devices can and will improve the performance of ESM and shared aperture receiver systems. For the near term the most promising candidate for the reference Channelized Cued ESM receiver system is an HTS IF Delay line that can provide 200 nanoseconds of delay across a 3 to 5 GHz band. Such a delay line can improve sensitivity by 1 to 2 dB while providing about a 6 dB improvement in two tone dynamic range. Perhaps even of greater importance is that the low device loss combined with the elimination of multiple amplifiers previously needed to overcome loss can significantly improve the amplitude and phase tracking of the delay lines.

In future systems it is unlikely that a single HTS device will be employed. Rather, it is more likely that large portions of the RF architecture will be placed in a cooler as a means of achieving performance and cost advantages. This is thought to include an HTS front-end, conventional IF amplifier, and HTS IF receivers. Looking even further in the future it is likely that entire HTS receivers will be remotely located with their HTS antennas and only digits will be returned to central for processing.